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MACCS2 Computer Code Application Guidance for Documented Safety Analysis

Interim Report

U.S. Department of Energy

Office of Environment, Safety and Health

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FOREWORD

This document provides guidance to Department of Energy (DOE) facility analysts in the use of the MACCS2 computer code for supporting Documented Safety Analysis applications. Information is provided herein that supplements information found in the MACCS2 documentation provided by the code developer. MACCS2 is one of six computer codes designated by the DOE Office of Environmental, Safety and Health as a toolbox code for safety analysis.

Suggestions for corrections or improvements to this document should be addressed to –

Chip Lagdon
EH-31/GTN
Office of Quality Assurance Programs
U.S. Department of Energy
Washington, D.C. 20585-2040
Phone (301) 903-4218
Email: Chip.Lagdon@eh.doe.gov

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EXECUTIVE SUMMARY

The Defense Nuclear Facilities Safety Board issued Recommendation 2002-1 on *Quality Assurance for Safety-Related Software* in September 2002. The Recommendation identified a number of quality assurance issues for software used in the Department of Energy (DOE) facilities for analyzing hazards, and designing and operating controls that prevent or mitigate potential accidents. The DOE response to the Recommendation, *Implementation Plan for Recommendation 2002-1 on Quality Assurance for Safety Software at Department of Energy Nuclear Facilities*, commits to a number of actions to improve Software Quality Assurance (SQA) in safety analysis and design software. The development and maintenance of a collection, or "toolbox," of high-use, SQA-compliant safety analysis codes is one of the major commitments. In time, the DOE safety analysis toolbox will contain a set of appropriately quality-assured, configuration-controlled, safety analysis codes, managed and maintained for DOE-broad safety basis applications. The MELCOR Accident Consequence Code System (MACCS) code and its successor MACC2 are designated as toolbox codes.

The MACCS2 code is likely to require completion of quality assurance improvement measures before meeting current SQA standards. In the interim period before these changes are completed, MACCS2 is considered a useful asset in the support of safety basis calculations. To ensure appropriate application of the designated toolbox software, the Implementation Plan has committed to sponsoring a set of code-specific documents to guide informed use of the software, and supplement the available user's manual information.

The MACCS/MACCS2 guidance report includes the following:

- Applicability information for DSA-type analysis, specifically tailored for DOE safety analysis
- Code development information and SQA background
- Appropriate regimes and code limitations
- Valid ranges of input parameters consistent with code capability and DOE safety basis applications, and
- Default input value recommendations for site-independent parameters.

This report is supplemental to, and does not supersede, the existing suite of MACCS and MACCS2 documentation. However, use of the information contained here, although not

ensuring correct application of MACCS2 in every DOE consequence analysis context, will minimize potential user errors and further standardize the use of MACCS2 in appropriate regimes of applicability.

1.0 INTRODUCTION

In January 2000, the Defense Nuclear Facilities Safety Board (DNFSB) issued Technical Report 25, (TECH-25), *Quality Assurance for Safety-Related Software at Department of Energy Defense Nuclear Facilities* (DNFSB, 2000). TECH-25 identified issues regarding the state of software quality assurance (SQA) in the Department of Energy (DOE) Complex for software used to make safety analysis decisions and to control safety-related systems. Instances were noted in which computer codes were either inappropriately applied or were executed with incorrect input data. Of particular concern were inconsistencies in the exercise of SQA from site to site, and from facility to facility, and in the variability of guidance and training in the appropriate use of accident analysis software.

During the subsequent 2000 to 2002 period, survey information on SQA programs, processes, and procedures was collected as well as the initial elements to a response plan. However, to expedite implementation of corrective actions in this area, the DNFSB issued Recommendation 2002-1, *Quality Assurance for Safety-Related Software at Department of Energy Defense Nuclear Facilities* (DNFSB, 2002). As part of its Recommendation to DOE, the DNFSB enumerated many of the points noted earlier in TECH-25, but noted specific concerns regarding the quality of the software used to analyze and guide safety-related decisions, the quality of the software used to design or develop safety-related controls, and the proficiency of personnel using the software.

DOE has developed a series of actions that address the Board's concerns, contained in the Implementation Plan for the DNFSB Recommendation, *Implementation Plan for Defense Nuclear Facilities Safety Board Recommendation 2002-1.* Two of the actions include:

(i) identification of a set of accident analysis software that is widely used in the DOE Complex, and
(ii) issuance of code-specific guidance reports on the use of the "toolbox" codes for DOE facility accident analysis, identifying applicable regime in accident analysis, default inputs, and special conditions for use.

Safety analysis software for the DOE "toolbox" status was designated by the DOE Office of Environment, Safety and Health (DOE/EH) in March 2003 (DOE/EH, 2003). The supporting basis for this designation was provided by a DOE-chartered Safety Analysis Software Group in a technical report entitled, *Selection of Computer Codes for DOE Safety Analysis Applications*, dated August 2002 (See http://www.deprep.org/archive/rec/2002-1/NNSACCodes1.pdf), and includes the MELCOR Accident Consequence Code System (MACCS) code and its successor MACCS2.

It is believed that each code designated for the toolbox can be applied to accident analysis under the precautions and recommended input parameter ranges documented in the body of this report. This code-specific document will be maintained and updated until a minimum qualification SQA condition is achieved.

The contents of this report are applicable in the interim period until measures are completed to bring MACCS2 into compliance with defined SQA standards. The primary objective of the guidance report is to provide information on the use of MACCS2 for supporting DOE safety basis accident analysis. Specifically, the report contains:

- Applicability guidance for Documented Safety Analysis (DSA)-type analysis, specifically tailored for DOE safety analysis
- Appropriate regimes, recommended configurations
- Overcoming known vulnerabilities and avoiding code errors
- Valid ranges of input parameters consistent with code capability and DOE safety basis applications
- Default input value recommendations for site-independent parameters, and
- Citations of currently available SQA documentation.

This report is intended to complement existing MACCS2 user's documentation. Nevertheless, the full suite of MACCS and MACCS2 reports should be requested and utilized by the DOE safety analyst to best apply the capability of this software. Current MACCS and MACCS2 documentation is broader in the coverage of the full range of capabilities of MACCS2, and the spectrum of inputs needed depending upon the application, but lack targeted guidance for particular applications such as DOE DSA accident analyses. Furthermore, the goal of the MACCS2 guidance document is to identify limitations and vulnerabilities not found elsewhere.

MACCS/MACCS2 Guidance Document

The MACCS/MACCS2 guidance document is written using the following set of sections. The first section contains an introduction and background providing an overview of toolbox software in the context of 10 CFR 830. More information follows on the scope and purpose of this document. The next major section is a summary description of MACCS/MACCS2. A third section discusses applicable regimes for using MACCS/MACCS2 in performing accident analysis. A large section on default inputs and recommendations, emphasizing appropriate inputs for DOE applications, succeeds this section. Following this discussion are sections on special conditions for use of the software and software limitations. Several sample cases are then provided, followed by acronyms and definitions, references, and appendices.

1.1 Background: Overview Of Toolbox Software In Context Of 10 CFR 830

In the context of 10 CFR 830, the Nuclear Safety Management rule, the six computer codes designated by DOE/EH as toolbox software, will be of appropriate pedigree for support of safety basis documentation. After completion of the minimum required SQA upgrade measures for a toolbox code, the safety analyst would still need to justify the specific application with the code of interest, input parameters, and user assumptions, but many SQA burdens would be reduced from current requirements. The user would need to reference the toolbox code and version, identify compliance with their organization's SQA requirements and demonstrate that the code is being applied in the proper accident analysis context using appropriate inputs. The SQA pedigree would be sufficiently established for technical review purposes since the code is recognized as toolbox-supported.

Only six codes out of more than one hundred software packages applied in the DOE Complex for accident analysis purpose have been designated as "toolbox" codes. Other non-toolbox, dispersion and consequence software can still be applied in the context of support safety basis applications. However, each organization applying this category of software will need to demonstrate compliance with applicable SQA criteria, such as those applied to the toolbox software.

1.2 Scope

The MACCS/MACCS2 guidance report includes the following:

- Applicability information for DSA-type analysis, specifically tailored for DOE safety analysis
- Code development information and SQA background
- Appropriate regimes and code limitations
- Valid ranges of input parameters consistent with code capability and DOE safety basis applications, and
- Default input value recommendations for site-independent parameters.

1.3 Purpose

The MACCS and MACCS2 codes are part of the designated group of software to be placed in the DOE Safety Analysis Toolbox. Prior to being brought under configuration management in the toolbox, MACCS2 and other designated software will be part of a SQA review. In the interim before this review process is completed, MACCS2 can be still be applied for safety analysis purposes as long as the safety analyst understands the strengths and limitations of the software and is cognizant of the information provided in this report and documentation provided by the code developer. If it is decided that upgrades are warranted, MACCS2 will be brought under configuration control only after this process is completed. At this point, MACCS2 use will be encouraged over that of its predecessor.

Use of the information contained herein will not ensure correct use of MACCS2 in all analytical contexts. However, it should minimize potential user errors and the likelihood of use outside regimes of applicability.

1.4 Applicability

It is recognized that other computer codes besides MACCS/MACCS2 exist that perform similar type of atmospheric dispersion and radiological consequence calculations. Moreover, manual or electronic spreadsheet calculations can be a viable alternative to using a computer code for some accident analysis applications that involve releases of radiological material. The relative merits of using a different computer program or using a hand calculation for a given application is a judgment that must be made by the analyst on a case-by-case basis. The U.S. Department of Energy (DOE) has provided guidance and general recommendations in this area through the Accident Phenomenology and Consequence (APAC) Methodology Evaluation Program. As part of this program, the radiological dispersion and consequence assessment (RDCA) Working Group (WG) was established to address issues and evaluate methodologies in the RDCA domain. The RDCA WG (also referred to as WG 5) issued a report that identifies and evaluates methodologies and computer codes to support RDCA applications (O'Kula, 1998).

The RDCA WG 5 report identified the MACCS/MACCS2 computer codes as recommended software with generally broad suitability to safety basis documentation applications. In addition to code recommendations, the report also provides a broad set of recommended "best practices" for modeling radiological releases to the atmosphere.

This report builds upon the WG 5 work to provide guidance and recommendations that are targeted to the use of the MACCS/MACCS2 for atmospheric dispersion and radiological consequence calculations in the context of DSA-type applications. Specifically, the guidance is best suited for:

- Consequence analysis calculations
- Mitigated and unmitigated hazard analysis
- Bounding analysis for final hazard categorization, and
- Confirmatory calculations for evaluating mitigative and preventive safety controls.

2.0 SUMMARY DESCRIPTION OF THE MACCS2 CODE

This section provides a summary form description of the MACCS2 code. It assumes an understanding of the principles of source term development from postulated accident conditions, the interface with dispersion conditions in the atmosphere, and the overall assessment of radiological dose to receptors. These concepts are discussed in Appendix A to DOE Standard 3009-94 (DOE, 2000).

Users requiring additional background information on dispersion and consequence analysis before reviewing input file preparation are referred to Appendix A in this document, "Overview of Atmospheric Dispersion and Consequence Analysis".

2.1 MACCS/MACCS2 Summary Description

MACCS2 (Chanin, 1998) is an IBM PC compatible based radiological atmospheric dispersion and consequence code. MACCS2 is written in FORTRAN 77 and 90 and is under development at Sandia National Laboratories (SNL) as an update to MACCS.[1] Since the issuance of DOE-STD-3009-94 for nuclear facility accident analysis, MACCS2 has been used for DOE applications primarily as a tool for deterministic consequence analysis. This information is used to support decision-making on control selection in nuclear facilities, specifically identification of safety structures, systems, and components (SSCs).

MACCS2 predicts dispersion of radionuclides by the use of multiple, straight-line Gaussian plumes. The direction, duration, sensible heat, and initial radionuclide concentration may be varied from plume to plume. Crosswind dispersion is treated by a multi-step function and both wet and dry depositions features can be modeled as independent processes. For DSA applications, the MACCS2 user can apply either the Latin Hypercube Sampling (LHS) mode or the stratified random sampling mode to process one year of site-specific meteorological data. Based on the meteorological sampling of site-specific data, and application of user-specified dose and/or health effects models, complementary cumulative distribution functions (CCDFs) are calculated for various measures of consequence. The average, median, 95th, and 99.5th percentile doses are provided in the output.

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[1] The United States Nuclear Regulatory Commission (NRC) sponsored the development of the MACCS code (Chanin, 1990; Jow, 1990; Rollstin, 1990; and Chanin, 1993) as a successor to the CRAC2 code for the performance of commercial nuclear industry probabilistic safety assessments (PSAs). The MACCS code was used in the NUREG-1150 PSA study (NRC, 1990a) in the early 1990's. Prior to the code being released to the public, the MACCS code was independently verified by Idaho National Engineering and Environmental Laboratory (Dobbe, 1990). After verification, the NRC released MACCS, Version 1.5.11 for use by the public. Examples of MACCS applied in this period include commercial reactor PSAs (both U.S. and international), as well as non-reactor nuclear facilities (primarily U.S.).

The major enhancements in the MACCS2 code over its MACCS predecessor are in the number of nuclides included in the dose conversion factor database, the number of daughters in the decay chain, the emergency response model, the food pathway model, and the inclusion of consequences from meteorological data in a sector as opposed to the whole site.

Other features that have been added to MACCS2 as well as those retained from MACCS are noted in Section 2.2. Table 2-1 contains summary information on MACCS2, based on the software package available from the Radiation Safety Information Computational Center (RSICC).

Table 2-1. Summary Description of MACCS2 Software

Type	Specific Information
Code Name	MACCS2 - MELCOR Accident Consequence Code System for the Calculation of the Health and Economic Consequences of Accidental Atmospheric Radiological Releases
Developing Organization and Sponsor	Sandia National Laboratories (SNL) for the U.S. Nuclear Regulatory Commission (primary) and U.S. Department of Energy (minor)
Version of the Code	Version 1.12
Auxiliary Codes	AUXILIARY CODES: DOSFAC2: NRC dose conversion factor (DCF) preprocessor. FGRDCF: DCF preprocessor based on the DCF databases of Federal Guidance Reports 11 and 12 from ORNL (DLC-172). IDCF2: DCF preprocessor based on the IDCF code developed at the Idaho National Engineering Laboratory. COMIDA2: Food pathway preprocessor based on the COMIDA (PSR-343) food pathway preprocessor developed at the Idaho National Engineering Laboratory.
Software Platform/Portability	FORTRAN 77/90, PC based some system dependencies
Coding and Computer	Fortran 77, PC based 80486 or Pentium processor (C00652/PC486/00).
Technical Support	Nathan Bixler Sandia National Laboratories P.O. Box 5800 Albuquerque, NM 87185-0748 (505) 845-3144 nbixler@sandia.gov;
Code Procurement	Radiation Safety Information Computational Center (RSICC) Oak Ridge National Laboratory Post Office Box 2008 Bethel Valley Road Oak Ridge, Tennessee 37831-6171 Phone: 865-574-6176; Fax: 865-241-4046 Email: pdc@ornl.gov
Code Package	CCC-652; Included are the references cited below and the Fortran source code, executables and data, which are distributed on 1 CD in self-extracting compressed DOS files.
Contributors	Sandia National Laboratories, Albuquerque, New Mexico, Oak Ridge National Laboratory, Oak Ridge, Tennessee, Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho.

Table 2-1. Summary Description of MACCS2 Software (Continued)

Documentation Supplied with Code Transmittal	1. D. Chanin and M. L. Young, "Code Manual for MACCS2, User's Guide," NUREG/CR-6613, Vol. 1, SAND97-0594 (May 1998). 2. D. Chanin and M. L. Young, "Code Manual for MACCS2, Preprocessor Codes COMIDA2, FGRDCF, IDCF2," NUREG/CR-6613, Vol. 2, SAND97-0594 (May 1998). 3. M. L. Young and D. Chanin, "DOSFAC2 User's Guide," NUREG/CR-6547, SAND97-2776 (December 1997). 4. H-N. Jow, J. L. Sprung, J. A. Rollstin, L. T. Ritchie, D. I. Chanin, "MELCOR Accident Consequence Code System (MACCS), Model Description," NUREG/CR-4691, SAND86-1562, Vol. 2 (February 1990). 5. J. Gregory, "Software Defect Notifications" (May 1998). M. L. Young, "READMAC2.txt" (April 1997). 6. Supplemental: M. L. Young and D. I. Chanin, "DOSFAC2 User's Guide," NUREG/CR-6547 (SAND97-2776, Sandia National Laboratories, Albuquerque, NM. 7. D. I. Chanin and M. L. Young, "Code Manual for MACCS2: Volume 2, Preprocessor Codes COMIDA2, FGRDCF, and IDCF2," NUREG/CR-6613, vol. 2 (SAND97-0594) Sandia National Laboratories, Albuquerque, NM.
Nature of Problem	MACCS2 simulates the impact of accidental atmospheric releases of radiological materials on the surrounding environment. This package is a major enhancement of the previous CCC-546/MACCS 1.5.11 package. The principal phenomena considered in MACCS are atmospheric transport, mitigative actions based on dose projection, dose accumulation by a number of pathways including food and water ingestion, early and latent health effects, and economic costs. MACCS can be used for a variety of applications including probabilistic risk assessment (PRA) of nuclear power plants and other nuclear facilities, sensitivity studies to gain a better understanding of the parameters important to PRA, and cost benefit analysis.
Method of Solution	MACCS contains simple models with convenient analytical solutions. A MACCS calculation consists of three phases: input processing and validation, phenomenological modeling and output processing. The phenomenological models are based mostly on empirical data, and the solutions they entail are usually analytical in nature and computationally straightforward. The modeling phase is subdivided into three modules. ATMOS treats atmospheric transport and dispersion of material and its deposition from the air utilizing a Gaussian plume model with Pasquill-Gifford dispersion parameters. EARLY models consequences of the accident to the surrounding area during an emergency action period. CHRONC considers the long term impact in the period subsequent to the emergency action period. Detailed meteorological, population, and economic and health data are required depending upon the type of analyses to be performed and output required. Model parameters can be provided by the user via input facilitating the analysis of consequence uncertainties due to uncertainties in the model parameters.

Table **2-1. Summary Description of MACCS2 Software (Continued)**

Restrictions or Limitations	The atmospheric model included in the code does not model the impact of terrain effects on atmospheric dispersion. The code also does not model dispersion close to the source (less than 100 meters from the source) or long range dispersion. The economic model included in the code models only the economic cost of mitigative actions.
Run Time	One source term for one meteorological sequence requires approximately 20 seconds on a Pentium 133 MHZ. Running one source term and sampling a year of weather data requires approximately 20 minutes.
Computer Hardware Requirements	IBM compatible 80486 or Pentium PC with 8 MB of RAM. Approximately 30 MB of hard disk space is required to load the complete MACCS2 package. Approximately 11 MB of hard disk space is required to load MACCS2 without the preprocessors included in the MACCS2 package.
Computer Software Requirements	The MACCS2 software was developed in a DOS environment. Lahey F77L-EM/32 Version 5.2 compiler was used to create the executables included in the package, which run successfully in the DOS window of Windows 3.1, Windows95 and WindowsNT. The programs can also be compiled with the Microsoft Powerstation Fortran 1.0a compiler.
Other Versions Available	MACCS 1.5.11.1 (PC486); MACCS 1.5.11.0 (IBM RISC)

2.2 OVERVIEW OF MACCS/MACCS2 FOR REGULATORY APPLICATIONS

For regulatory applications, the MACCS/MACCS2 codes are used to calculate the fifty-year Total Effective Dose Equivalent (TEDE) to specified stationary receptors from hypothetical atmospheric releases of radioactivity. The radiological dose is reported in DSA applications. The TEDE is calculated for both onsite and offsite receptors using standard uptake assumptions and dose conversion database values. Sensitivity studies may also be performed with MACCS/MACCS2 models to show the relative benefits of evacuation, sheltering, interdiction, and the effects of various shielding assumptions, although these models are generally not invoked in standard DSA applications.

The MACCS/MACCS2 codes predict dispersion of radionuclides by the use of multiple, straight-line Gaussian plumes. The direction, duration, sensible heat, and initial radionuclide concentration may be varied from plume to plume. Crosswind dispersion is treated by a multi-step function and both wet and dry depositions features can be modeled as independent processes. Meteorological variability can be treated in MACCS/MACCS2 with a stratified random sampling algorithm. Based on the sampled distribution, and application of user-specified dose and/or health effects models, complementary cumulative distribution functions (CCDFs) are calculated for various measures of consequence. The 50th (median), 90th , 95th, 99th, and 99.5th percentile doses are provided in the output as well as the mean and peak values.

Dose conversion factors (DCFs) relate environmental concentrations and intakes to resultant human doses for specific exposure pathways, organs, and radionuclides. Doses arise from both internal and external exposures. The internal exposures consist of inhalation (from the plume and from resuspension) and ingestion. The external exposures are from cloudshine, groundshine, skin deposition, and direct (prompt) radiation from a criticality.

A total of 825 radionuclides and models for decay chains are included in MACCS2. MACCS2 models decay chains up to six generations taking into consideration half-lives, decay products, and branching ratios for those decay products. MACCS, in contrast, models a smaller number of decay chains and is limited to simple parent-daughter decay (i.e., two-member chains).

The MACCS/MACCS2 code makes use of an input file that contains Inhalation DCFs (IDCFs) as well as DCFs for ingestion and dose coefficients for cloudshine and groundshine. Typically inhalation is the dominant pathway for dose, and recommended sources for the IDCFs are given in Section 4 of this report.

The major enhancements in the MACCS2 code include more user options on initializing the geometry and size of the plume and in specifying the system of dispersion parameters through a look-up table. Other output types that are also capable of being output with MACCS2 are:

- the output of the atmospheric dispersion data in a complementary cumulative distribution function (CCDF)
- the sector independent peak dose for any organ, and the
- sector-dependent peak dose for any organ.

3.0 APPLICABLE REGIMES

The objective of this section is to present a discussion of MACCS2 applicability from two perspectives: (1) in terms of its overall function as a key step in accident analysis; and (2) noting the phenomenological regimes in which it provides an approximate model of dispersion in the environment and the resulting radiological exposure to downwind individuals (receptors).

3.1 Overall Application in Safety Analysis

The Department of Energy (DOE) evaluates and approves the operation of its nuclear facilities via the safety analysis process outlined in DOE Rule, 10 CFR 830 – Subpart B and DOE-STD-3009-94. This safety analysis process requires the development of a Documented Safety Analysis per the Rule language and includes two key types of analyses: (1) hazard analysis and (2) accident analysis.

Hazard analysis is the cornerstone of the DOE safety analysis process and is largely a qualitative process by which

- the hazards in the facility are identified,
- a spectrum of accidents are postulated for each hazard,
- a qualitative evaluation of accident likelihood and consequence is made, and
- all preventive and mitigative systems or controls are identified along with a qualitative measure of their importance.

The final product of the hazard analysis gives rise to a list of which systems or controls are important to safety and therefore are designated as safety-significant. This designation will lead to a formal commitment on the part of the facility contractor to maintain the safety function of these systems through technical safety requirements (TSRs).

Accident analysis is a follow-on activity to the hazard analysis. The focus of the DBAs is public exposure, and therefore, a quantitative calculation of dose to the maximally exposed offsite individual (MOI) is made for each DBA. The purpose of the dose calculations is to determine if some of the safety-significant systems identified in the hazard analysis should have their safety designation raised to safety-class. The standard approach for the accident analysis is outlined below in terms of the source term and the radiological dispersion and consequence analysis phases.

3.1.1 Source Term Analysis

The radiological consequences are typically established using the methods discussed in the DOE-HDBK-3010-94 (DOE, 1994a). Since the dose from the inhalation pathway will usually dominate the overall dose from most non-reactor facilities, the source term may be quantified using from the five-factor formula:

$$ST = MAR \cdot DR \cdot ARF \cdot RF \cdot LPF \quad \text{(Equation 3-1)}$$

where:

- Source term (ST) is the total quantity of respirable material released to the atmosphere during the postulated accident condition.
- Material-at-Risk (MAR) is the total quantity of radionuclides (in grams or curies of activity for each radionuclide) available to be acted on by a given physical stress.
- Damage Ratio (DR) is the fraction of the MAR actually impacted by the accident-generated conditions.
- Airborne Release Fraction (ARF) is the fraction of a radioactive material suspended in air as an aerosol and thus available for transport due to a physical stress from a specific accident condition.
- Respirable Fraction (RF) is the fraction of airborne radionuclides as particles that can be transported through air and inhaled into the human respiratory system and is commonly assumed to include particles 10-μm Aerodynamic Equivalent Diameter (AED) and less.
- Leakpath Factor (LPF) is the fraction of the radionuclides in the aerosol transported through some confinement deposition system (e.g., facility rooms, ductwork) or filtration mechanism (e.g., HEPA or sand filters).

For most accident analyses the MAR is best defined as the maximum inventory that is permitted within the room, area or facility. While it is permissible to exclude material forms that are considered to be unaffected by an accident condition from the MAR, experience suggests that for these forms the DR is usually best set to zero for the release mechanism. The overall result using either approach is the same, but by assigning DR values to each combination of inventory form and release mechanism, there is the expectation that each credited form (e.g., a shipping package that is certified to withstand the postulated fire severity) is also reviewed against secondary events (e.g., building collapse initiated by a fire) and therefore, less likely to be overlooked.

The ARF and RF values presented in DOE-HDBK-3010-94 are derived from discrete experiments that typically evaluated a single release mechanism. For example, in a severe fire there may be many mechanisms occurring simultaneously. Powdered metals might be subject to entrainment by fire-induced air currents, falling because of equipment (glove box) collapse, and impact because of objects falling into the exposed fire. In addition, multiple occurrences could occur for specific mechanisms (e.g., impact of falling object on a stable powder). Aqueous solutions could be subject to boiling within the storage tank, spillage because of a tank collapse, and rapid evaporation plus splashing as the liquid sits in a diked area during the same postulated fire. Solid metals can be subject melting, dripping and burning during the same event. To accommodate multiple-mechanism events, it is common to consider the ARF and RF values for each mechanism in the source term estimate.

Just as with the (ARF·RF) term, there can be multiple LPF terms applied to a single material form (e.g., room leakage, ventilation system deposition, filtration system effectiveness). Thus, their cumulative effect must be accounted for. There can be interdependence between the LPF and DR in some applications. If a shipping package is considered to leak during a fire, the leakpath effect as the material exits the packaging can be accounted for as an LPF or a DR. Based on experience, it is recommended that source term reductions related to localized conditions such as at shipping packages, and glove boxes be accounted for in the DR term. This approach allows the source term contribution from individual rooms to be readily compared. It also simplifies comparisons between the room source term and the building source term.

Based on the above discussion, Equation (1) can be generally reformatted as:

$$ST_{jk} = \sum_{i=1}^{n_i} \left\{ MAR_{ij} \cdot DR_{ijk} \cdot \left[(ARF \cdot RF)_{ijk} \cdot \left(\sum_{m=1}^{n_m} LPF_m \right)_{ijk} \right] \right\} \quad \text{(Equation 3-2)}$$

where:

- i is the MAR component in a specific form
- j is the MAR component by type (e.g., Pu_{238}, Pu_{239})
- k is the release mechanism
- m is the filtration or deposition stage
- n is the number of parameters for the form, type, mechanism or stage based on the subscript.

Thus, the source term is usually expressed in terms of an isotopic activity distribution for each release mechanism. Source term components that are associated with the same release duration can be combined, but source term components that have different release mechanisms should be kept separate to account for time-dependent variance in atmospheric dispersion for consequence assessment.

Note that the DR, but not the MAR, is shown in Equation (2) as a function of the release mechanism (k subscript), based upon the recommendation above on how to best handle the interplay between the MAR and the DR. Frequently, the DR, ARF, RF, and LPF terms are specified independently of the type, and the j subscript can be dropped from these terms as applicable.

3.1.2 Dispersion and Consequence Analysis

Once the source term is established, the consequences to the receptors can be estimated. For fires scenarios at facilities with relatively short distances to the site boundary, the receptor at the site boundary may be exposed to lower concentrations as a result of plume buoyancy that can cause lofting of the plume above the receptor. Under these circumstances, higher receptor exposures can be expected downwind of the site boundary as the effects of increasing downwind plume growth progressively makes plume rise effect less significant. The touchdown point refers to the location of maximum receptor concentration. Thus, the maximally exposed individual for a lofted plume is not at the site boundary, but rather at the touchdown point. Rather than evaluating for this point, it can be more cost effective to estimate the fire consequences as a ground level release with the maximally exposed individual at the site boundary. While the results will be higher than the plume-buoyancy credited analysis, the increase may not be significant when compared to the uncertainties in the analysis and the analysis complexity.

Typically the off-site radiological consequences are expressed as the total effective dose equivalent (TEDE) to the receptor at the highest exposure conditions. For most accident types this is at or near the site boundary. The TEDE includes the 50-year committed effective dose equivalent (CEDE) from inhalation both during plume passage and later from resuspension, the cloudshine effective dose equivalent (EDE), the groundshine EDE, and the skin absorption EDE. This TEDE calculation does not include the ingestion CEDE from consumption of contaminated water and foodstuffs. The inhalation CEDE is usually the dominant contributor and its relationship to the source term is highlighted below.

The basic equation for the radiological consequences to an individual receptor (i.e., stationary at a specific downwind location) from the inhalation pathway during plume passage is:

$$\text{Receptor Inhalation CEDE} = \text{BR} \cdot \sum_{k=1}^{n_k} \left\{ \left(\frac{\chi}{Q} \right)_k \cdot \sum_{j=1}^{n_j} \left[\text{ST}_{jk} \cdot \text{C}_j \cdot \text{IDCF}_j \right] \right\}$$

(Equation 3-3)

where: j, k, n are as defined in Equation 3-3 above

BR is the breathing rate of the individual exposed to the plume of released radiological material, with typical units of m^3/s.

C_j is the specific activity of isotope j, with typical units of Ci/kg if ST is in mass units (kg) and unity if ST is in activity units (Ci).

$IDCF_j$ is the inhalation dose conversion factor for unit activity uptake of isotope j, with typical units of [rem/Ci] or [Sv/Bq].

$(\chi/Q)_k$ is the downwind dilution factor from atmospheric dispersion, which represents the time-integrated concentration at a specific downwind location that is normalized by the quantity released to the atmosphere, with typical units of s/m^3.

When the ST value is input into the MACCS2 code, the MACCS2 output provides the TEDE values at the requested receptor locations that will include the contribution from the plume-passage inhalation CEDE as well as the contributions from resuspension inhalation CEDE, cloudshine EDE, groundshine EDE, and skin absorption EDE.

The sequence of steps that are outlined above represents the recommended approach for calculating receptor consequences. Sometimes for matters of convenience, other approaches besides direct input of the ST value into the MACCS code are used to calculate consequences. Two of these are described below. An advantage that both these approaches share is that they allow for MACCS consequence calculations to be performed independently of the source term calculations, which is a consideration when faced with a demanding schedule.

Recall that the DR, ARF, RF, and LPF terms are frequently specified independently of the type, and the j subscript can be dropped from these terms in Equation (2). Sometimes under these circumstances, an analyst uses a normalized MAR that equals the MAR divided by the total inventory mass or total inventory volume and inputs the normalized MAR into the MACCS calculation. Under these circumstances, the consequence calculations of MACCS yield normalized TEDE values that represent the receptor TEDE per unit quantity of mass or volume of respirable material that is released to the atmosphere for each release mechanism. The product of these TEDEs with the corresponding source term mass or volume (ST quantity as defined by Equation (3-4) below) will yield the receptor dose for each of the release mechanisms.

$$(\text{ST quantity})_k = \sum_{i=1}^{n_i} \left\{ (\text{inventory mass or volume})_i \cdot \text{DR}_{ik} \cdot \left[(\text{ARF} \cdot \text{RF})_{ik} \cdot \left(\sum_{m=1}^{n_m} \text{LPF}_m \right)_{ik} \right] \right\}$$

(Equation 3-4)

and

$$\text{Receptor TEDE} = \sum_{k=1}^{n_k} \left\{ (\text{ST quantity})_k \cdot (\text{normalized TEDE})_k \right\}$$

(Equation 3-5)

Another approach that is sometimes employed is to individually input unit activity values of the inventory into the MACCS code for each release mechanism to yield unit-activity TEDEs. Recall, that the release duration that is associated with each release mechanism is a variable that factors into the χ/Q value that is calculated by MACCS. So, unit-activity TEDEs must be calculated individually for the various time durations that represent the various release mechanisms. With the unit-activity approach, the following equation is used to determine the receptor consequences.

$$\text{Receptor TEDE} = \sum_{j=1}^{n_j} \sum_{k=1}^{n_k} \left\{ \text{ST}_{jk} \cdot (\text{unit TEDE})_{jk} \right\}$$

(Equation 3-6)

3.1.3 Computer Codes for Accident Analysis

The safety analyst may use hand calculations or computer codes to calculate source term and dispersion values. The computer codes chosen by the safety analyst fall into several categories. The categories of codes are

- radiological atmospheric dispersion codes,
- chemical atmospheric dispersion codes,
- fire modeling codes, and
- leak-path analysis codes.

The analyst typically applies one or more of these types of codes to calculate parameters such as DR, LPF, and χ/Q, or to integrate over groups of these parameters. The effect of the quality of these codes on the overall safety analysis process can be evaluated qualitatively by examining the role that these parameters play in the overall safety process.

Qualitative Effect of the Codes on Safety Analysis

The gross effect of the use of computer codes can be evaluated by examining their effect on the final MOI dose values calculated as part of the accident analysis. The values chosen or calculated for each parameter in the dose equation are near the conservative tail of any distribution that would be assigned to the individual parameter. Therefore, when each parameter is multiplied using the five-factor formula to obtain the dose, the conservatism in the calculation grows. If applied consistently in each phase of the process and in a reasonably bounding manner, this large conservatism in the calculation has always provided the DOE safety analysis process with sufficient margin when the doses are used to make decisions regarding safety. Even if a single value in the dose calculation were off by an order of magnitude, the resulting value would still not approach the mean value of dose if a cumulative distribution of dose also were calculated.

MACCS2 is used to calculate the appropriate dilution factor and ultimately quantify the radiological dose. Their net effect on safety then is related to their input in selecting safety-class systems, structures, and components (SSCs).

MACCS2 and other atmospheric dispersion and radiological consequence codes are used in analyzing atmospheric dispersion and the subsequent radiological consequence of accidental releases of radioactivity from postulated accident conditions. Codes of this type of are used primarily to calculate the appropriate dilution factor for atmospheric transport of puffs or plumes and ultimately quantify the radiological dose that is received by the maximally exposed offsite individual (MOI). The 95^{th} percentile of the distribution of doses to the MOI is the comparison point for assessment against the evaluation guideline (EG). Consequently, the importance of these class of accident analysis codes on safety is related to their contribution in selecting safety-class systems, structures, and components (SSCs).[2]

Appendix A to DOE-STD-3009-94 prescribes the statistical method to be used to calculate the MOI dose, which is based on the method described in Position 3 of the U.S. Nuclear Regulatory Commission Regulatory Guide 1.145 (February 1983). Given site-specific data, the 95th percentile consequence is determined from the distribution of meteorologically-based doses calculated for a postulated release to downwind receptors at the site boundary that would result in a dose that is exceeded 5% of the time. Appendix A to DOE-STD-3009-94 allows for variations in distance to the site boundary as a function of distance to be taken into consideration. Assuming the minimum distance to the site boundary applies in all directions is a conservative implementation that is easily supported by MACCS2 and that essentially makes the calculations sector independent.

[2] The selection of safety-class SSCs is an important decision, but the decision to make an SSC safety-significant is made initially in the hazard analysis. Thus, the quality of the dose value will not affect the SSC being made a safety-significant SSC and having TSR coverage, only the designation of safety-class, and therefore, possibly the pedigree of the SSC.

3.2 Phenomenological Regimes of Applicability

The MACCS2 class of atmospheric dispersion codes is based on the Gaussian model of dispersion. As such, these types of computer model are best suited for specific types of conditions. The chief phenomenological regimes for applying MACCS2 include:

- Temporal regime – The use of these codes is best suited for "short" duration plumes, ranging from approximately several minutes to several days.

- Spatial regime - The class of code also does not model dispersion close to the source (less than 100 meters from the source), especially where the influence of structures or other obstacles is still significant. Dispersion influenced by several, collocated facilities, within several hundred meters of each other should be modeled with care. Similarly, the MACCS2 class of codes should be applied with caution at distances greater than ten to fifteen miles, especially if meteorological conditions are likely to be different from those at the source of the release. Long-range projections of dose conditions are better calculated with mesoscale, regional models that are able to account for multiple weather observations. Nevertheless, some applications may require fifty-mile or greater radius analysis to meet requirements, e.g. Environmental Impact Statements (EISs).

- Terrain variability – Gaussian models are inherently flat-earth models, and perform best over regions of transport where there is minimal variation in terrain.

- Energetic releases – MACCS2 does not account for momentum-driven releases or those originating from detonation type events without appreciable post-processing of boundary and initial conditions. Using the latter approach, Steele (1998) has demonstrated a MACCS2-based, segmented methodology for a detonation source term that was found to compare well with observations.

- Thermal buoyancy - In plumes arising from fire-related source terms, the user should exercise caution with the models such as MACCS2 that use the Briggs algorithm. The Briggs approach for accounting for sensible energy in a plume is valid for "open-field" releases (not impacted by buildings and other obstacles), or if used in combination with building wake effects. Appendix C provides a limited sensitivity study of the effects of buoyancy and building wake effects on plume dispersion.

- Dose conversion factor applicability – The user should ensure that the dose conversion factors used in MACCS2 are applicable to the radionuclides in the source term and the physicochemical characteristics. For example, plutonium nitrates and oxides have different time scales for dosimetric effects in the body. Thus, the appropriate lung absorption type should be used in the dose conversion factor file used in the MACCS2 run.

4.0 INPUTS AND RECOMMENDATIONS

4.1 MACCS/MACCS2 CODE STRUCTURE

MACCS and MACCS2 are executed in a three-step method on the personal computer. Air and ground concentrations, plume size, and timing information for all plume segments as a function of downwind distance are calculated in the first step **ATMOS**. The next step is **EARLY**; this calculation accounts for consequences due to exposure to radiation in the emergency phase (first 7 days) of the accident. The last step is **CHRONC**. Its purpose is to calculate consequences due to exposure to radiation subsequent to the emergency phase of the postulated accident and for computing decontamination and other economic impacts incurred because of the accident. The complete three-step execution of MACCS and MACCS2, including input and output files, is shown in Figures 4-1 and 4-2, respectively. For support of a DSA, post-emergency doses are not of interest, thus the CHRONC module is not executed. In addition, a uniform population density is assumed, eliminating the need for a separate population input file.

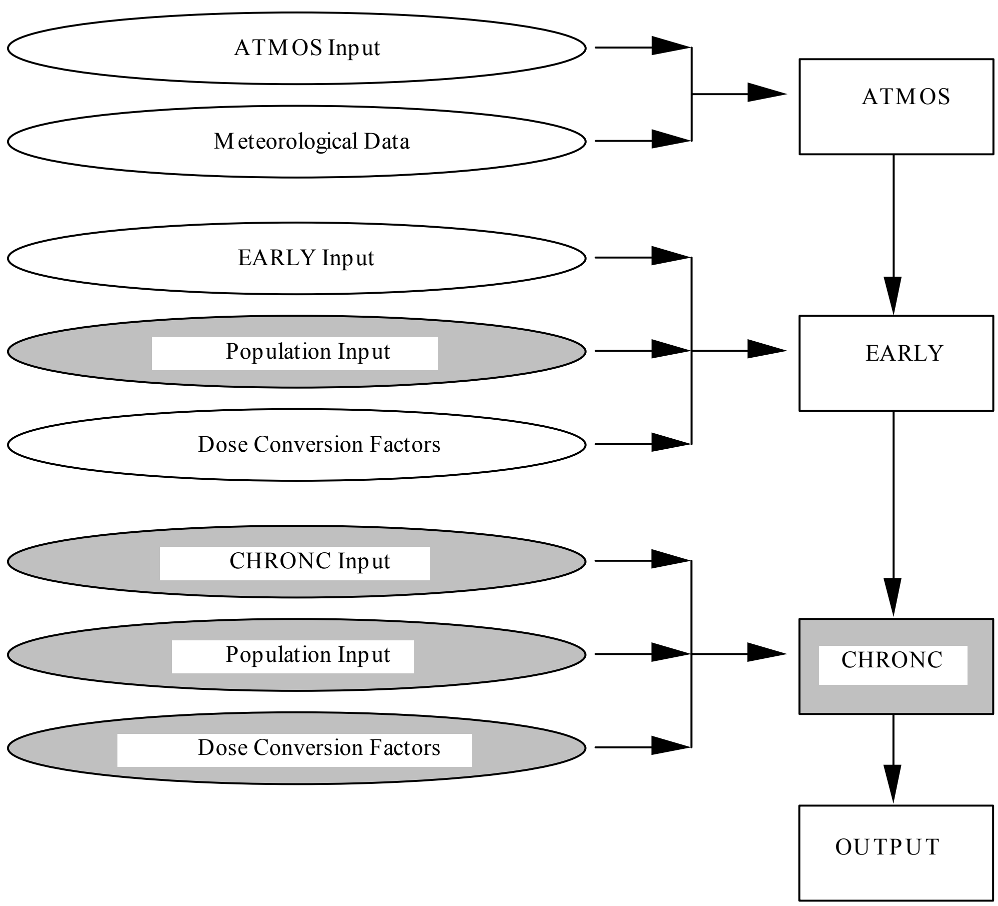

Figure 4-1. Flow Chart of the MACCS Three-Step Execution and Input Files

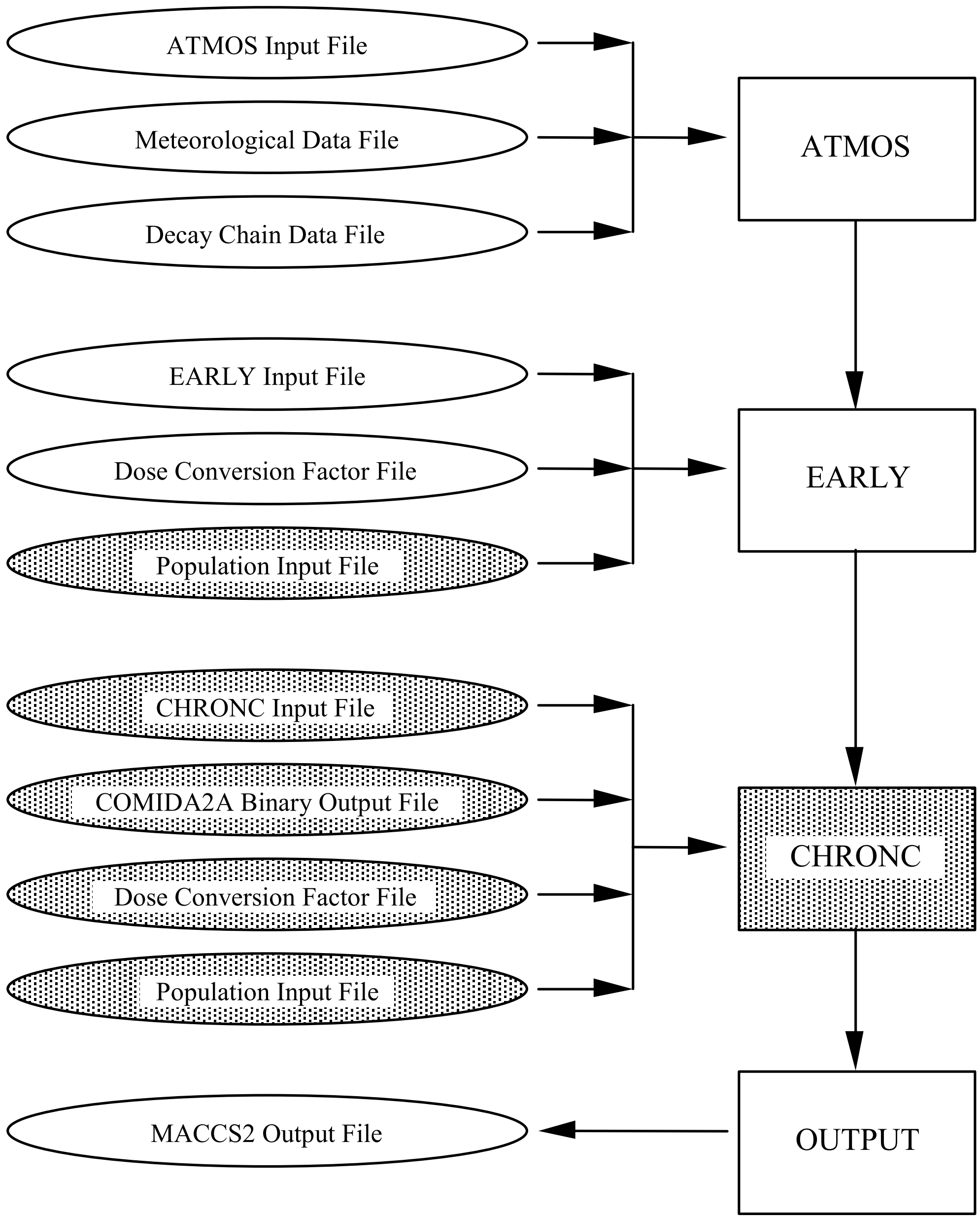

Figure 4-2. Flow Chart of the MACCS2 Three-Step Execution and Input Files

4.2 GENERAL CODE INPUT AND OUTPUT ASSUMPTIONS

For input into Safety Basis documents, the MACCS2 code is executed through the EARLY module. In the following section, standard MACCS2 ATMOS and EARLY module input files are discussed line by line. The particular input file commented upon here is used because it is the sample file supplied with the software package from the RSICC software center. In the lines that follow, the phrase, "These values should not be changed" or "This value should not be changed" is a recommendation to the user to not make any changes to the corresponding line of input in the RSICC-supplied file.

Only a limited number of input parameters need be changed for a specific MACCS execution. Of those parameters that are changed for a specific MACCS2 case, most will be related to the source term being released or more specifically the radionuclide inventory being released. When defining the radionuclide inventory for MACCS2 input, one must consider the activity of the inventory, under what conditions the material is being released (i.e. filtered or unfiltered conditions), and the material type being released. The material type influences the selection of CEDE inhalation dose conversion factors (IDCFs).

For documented safety analysis purposes, the consequences of interest are the centerline Total Effective Dose Equivalent (TEDE) incurred by the Maximally Exposed Offsite Individual (MOI) evaluated at the 95th quantile dose level. The MOI TEDE will most easily evaluated with MACCS2 at the closest site boundary without regard to sector (i.e., sector independent). Although this method is not fully compliant with NRC Regulatory Guide 1.145, the calculated dose at the closest offsite boundary without regard to sector can be shown to be conservative relative to that calculated with regard to sector.[3] For compliance with the specific NRC Regulatory Guide 1.145 positions with regard to sector-dependent doses, post-processing of MACCS2 code output must be performed.

The sector-independent MOI TEDE output is requested in the EARLY input file through the Type 6 Number data block that in general provides the centerline dose at distance for various pathways. As discussed in the detailed coverage of the inputs that follows, the label "TOT LIF" is used to specify the total dose from all direct exposure pathways. MACCS2 automatically provides the mean, 50th percentile, 90th percentile, 95th percentile, 99th percentile, 99.5th percentile, and peak values. The user may also request a table showing the complementary cumulative distribution function (CCDF) in terms of consequence and probability pairs.

An edited output file, containing an echo of the input, is shown in Section 7. The case illustrates the MACCS2 calculation of a unit release of plutonium (^{239}Pu) for four different conditions:

---

[3] Each consequence analysis should evaluate the validity of this statement based on the location of the facility, the release height and the DOE reservation boundary. For example, for most Savannah River Site facilities, the degree of conservatism is approximately 8% - 10% (O'Kula, 2000).

ground-level release, ground-level release with sensible heat, ground-level release with building wake effects, and ground-level release with sensible heat and building wake effects. The example also provides an illustration of a sensitivity study where relatively few parameters are being changed.

This section of the report provides guidance for specifying inputs when using the MACCS2 computer code. Appendix D provides parallel guidance for specifying inputs when using the earlier version of the code, namely, MACCS 1.5.11.1.

4.3 GENERAL NOTES ON MACCS2 INPUT FILES

For MACCS2 the following conventions must be followed:

- All values not in quotes must be in UPPER case, except for the specification of the radionuclide names. MACCS2 radionuclide names are specified using uppercase letters for the first letter in the radionuclide symbol and lowercase for the second letter. In addition, the "m" metastable designation is also lower case.
- Quote marks should be single straight quote marks (i.e. 'input value') not smart quotes marks (i.e. ‘input value’).
- MACCS2 dose conversion factor files require fixed-format, and it is strongly recommended that input data files be converted to Word or Word Perfect files to display non-compliant spacing (insufficient or extra spaces) and tabs. The user can then convert back to the appropriate format prior to MACCS2 execution.
- Input files, although not fixed format, are easier to set up in Word or Word Perfect to eliminate unintentional tabs.

The MACCS2 naming convention for input parameters is as follows:

- Characters one and two indicate the date block
- Characters three to eight indicate the variable name (Occasionally in new MACCS2 variable names, characters one to nine are used to indicated the variable name and the data block nomenclature is dropped.)
- Characters nine to eleven indicate the line of data being entered (there must always be eleven characters in the input parameter name).

The MACCS2 naming convention for user requested output is as follows:

- Characters one to five indicate the output type
- Characters six to eleven indicate either the number of requested input or the specific output requested

The discussion in the remainder of this section is based on the MACCS2 User's Manual (Chanin, 1998).

4.4 ATMOS INPUT FILE

This section of the document addresses input file variables that may be changed for execution of MACCS2 for safety basis document applications. Also discussed are site-specific parameter inputs that are selected by the user for a specific location.

For each section of input, page-specific references to the MACCS2 User's Guide are provided. These will allow the DOE safety analyst to review the original report from the SNL code developer to check on a specific variable.

The particular ATMOS input file discussed in the following is used as a beginning baseline. It is one of the sample files (e.g., IN1A.INP) supplied with the MACCS2 software compact disc from RSICC. If a variable is not explicitly mentioned, it is not necessary to change its value in the file.

Run Identification Data Block (RI)

Variable ATNAM1 (ATMOS input file identifier line)

NUREG/CR-6613, Vol. 1 – page 5-3 Line within MACCS2 IN1A.INP sample file:

```
RIATNAM1001  'IN1A.INP, SURRY, SAMPLE PROBLEM A, ATMOS INPUT'
```

For a specific application:
Change to a descriptive title for this execution of MACCS2, observing the appropriate alphanumeric character length convention.

Geometry Data Block (GE)

Variable NUMRAD and SPAEND (Number of radial grid endpoints and locations of radial grid endpoints)

NUREG/CR-6613, Vol. 1 – pages 5-3 to 5-4
Lines within MACCS2 IN1A.INP sample file:

```
GENUMRAD001  26
*
GESPAEND001      .16       .52      1.21      1.61      2.13
GESPAEND002     3.22      4.02      4.83      5.63      8.05
GESPAEND003    11.27     16.09     20.92     25.75     32.19
GESPAEND004    40.23     48.28     64.37     80.47    112.65
GESPAEND005   160.93    241.14    321.87    563.27    804.67
GESPAEND006  1609.34
```

For a specific application:

If population data is being entered, the polar grid supplied with the MACCS2 code is adequate. However, distances past 80.5 km (50 miles) should be eliminated. Receptor locations closer than 100 m should not be attempted with this code, unless the dispersion parameter data set used is based on the appropriate measurements.[4] If a consequence at a single receptor point is required, the following lines, or similar lines, may be used:

```
GENUMRAD001  35
*
GESPAEND001    0.20   0.30   0.40   0.50   0.60   0.70   0.80
GESPAEND002    0.90   1.00   1.50   2.00   2.50   3.00   3.50
GESPAEND003    4.00   4.50   5.00   5.50   6.00   6.50   7.00
GESPAEND004    7.50   8.00   8.50   9.00   9.50  10.00  10.50
GESPAEND005   11.00  11.50  12.00  12.50  15.00  20.00  30.00
```

If the location of interest is not a midpoint of two of these endpoints, the two closest to the location may be changed.

Note:

If meteorological data is sampled based on binning of like conditions, values must be included here that are within 10% of the rain interval endpoints that are specified though the RNDSTS variable of the M4 data block.

For MACCS2, the endpoints must be at least 100 meters apart.

Radionuclide Data Block (IS)

Variable NUMISO (Number of radionuclides)

NUREG/CR-6613, Vol. 1 – page 5-4

Line within MACCS2 IN1A.INP sample file:

```
ISNUMISO001 60
```

For a specific application:

This is the number of radionuclides being released. This number must be 150 or less. If the number of radionuclides is greater than 150, either the inventory must be divided into groups with a maximum of 150 radionuclides, or only those radionuclides that contribute to the overall TEDE should be retained. A useful cut-off for considering a group of radionuclides is the dose consequence contributed by one or more radionuclide is ≤ 0.1%. Below this value the

[4] See Eimutis (1972), for example, for dispersion parameterization.

radionuclides in question can be ignored because they contribute insignificantly to the dose.

Variable WETDEP and DRYDEP (Wet and dry deposition flags for each group by DEPFLA)

NUREG/CR-6613, Vol. 1 – pages 5-5 to 5-6

Line within MACCS2 IN1A.INP sample file:

```
ISDEPFLA001    .FALSE.   .FALSE.
ISDEPFLA002    .TRUE.    .TRUE.
ISDEPFLA003    .TRUE.    .TRUE.
ISDEPFLA004    .TRUE.    .TRUE.
ISDEPFLA005    .TRUE.    .TRUE.
ISDEPFLA006    .TRUE.    .TRUE.
ISDEPFLA007    .TRUE.    .TRUE.
ISDEPFLA008    .TRUE.    .TRUE.
ISDEPFLA009    .TRUE.    .TRUE.
```

For a specific application:

For the noble gases group, both values should be set to ".FALSE." For the other groups, the first value should always be ".FALSE." indicating no wet deposition. When dry deposition is used, the second value should be set to ".TRUE."

Variable MAXGRP (Number of chemical groups)

NUREG/CR-6613, Vol. 1 – page 5-5

Line within MACCS2 IN1A.INP sample file:

```
ISMAXGRP001 9
```

For a specific application:

This is simply the total number of groups determined above with a minimum value of 1 (all radionuclides are modeled in the same manner) and a maximum value of 10. Typically this value will be 3 or less (group 1 – noble gases, group 2 – tritiated water vapor, and group 3 – all other radionuclides).

Variable NUCNAM, and IGROUP (Radionuclide name and chemical group as input by OTPGRP.

NUREG/CR-6613, Vol. 1 – pages 5-7 to 5-8

Note: The values of the parent radionuclide and half-life are input through an auxiliary input file)

Line within MACCS2 IN1A.INP sample file:

```
ISOTPGRP001     Co-58        6
ISOTPGRP002     Co-60        6
ISOTPGRP003     Kr-85        1
```

```
  .
  .
  .
ISOTPGRP060     Cm-244       7
```

For a specific application:

The selection of the chemical groups is based on similar release fractions and plume removal mechanisms (i.e. wet and dry deposition). For example, both noble gases and tritiated water vapor have a release fraction of 1.0, but the noble gases are not subjected to either removal mechanism while tritiated water vapor can be removed by both wet and dry deposition mechanisms. Thus, noble gases would be in one chemical group, and tritiated water vapor would be in another.

Variable NUMSTB and NAMSTB (Number of pseudo-stable radionuclides and the pseudo-stable radionuclides)

NUREG/CR-6613, Vol. 1 – page 5-7

Line within MACCS2 IN1A.INP sample file:

```
ISNUMSTB001      27
*
ISNAMSTB001     I-129    (daughter of Te-129 and Te-129m)
ISNAMSTB002     Xe-131m  (daughter of I-131)
ISNAMSTB003     Xe-133m  (daughter of I-133)
  .
  .
  .
ISNAMSTB027     Pm-147   (daughter of Nd-147)
```

For a specific application:

Pseudo-stable radionuclides will most often be defined as the first radioactive daughter of the radionuclides in the source term. The pseudo-stable radionuclide is used to shorten chains when the activity of the daughter products would not contribute significantly to the consequence associated with the whole source term. For example, in a seven-day decay period following the event, only 500 picograms of U-235 will have been produced through the decay of Pu-239. Thus, the calculation of consequences from the daughters of Pu-239 is not beneficial, as they will not contribute significantly to the total consequence.

Note:

Radionuclides listed as pseudo-stable should not be included in the source term radionuclide list.

Wet Deposition Data Block (WD)

NUREG/CR-6613, Vol. 1 – pages 5-5 to 5-6

These values should not be changed. In typical DSA applications, the data entered in this block is not used in the calculation because the WET DEPOSITION flag is 'FALSE'.

Dry Deposition Data Block (DD)

Variable NPSGRP (Number of dry deposition velocity groups)

NUREG/CR-6613, Vol. 1 – pages 5-9 to 5-10

Line within MACCS2 IN1A.INP sample file:

```
DDNPSGRP001   1
```

For general application:

Set this value to the maximum number of dry deposition velocities groups to be used in a majority of site analyses. Typically this value will be 3 (one group will be for releases passing through a filtration system; one group will be for releases straight to environment; and one group will be for tritiated water vapor).

Variable VDEPOS (Dry deposition velocities)

NUREG/CR-6613, Vol. 1 – page 5-10

Line within MACCS2 IN1A.INP sample file:

```
DDVDEPOS001   0.01   (VALUE SELECTED BY S. ACHARYA, NRC)
```

For general application:

Typically, the line will be:

```
DDVDEPOS001   0.001  0.005 0.010
```

The dry deposition velocity of 0.001 m/s is appropriate for releases passing through a filter before being released into the atmosphere as well as those not passing through a filter depending on release and environmental conditions. The 0.001-m/s deposition velocity is consistent with a particle with an aerodynamic equivalent diameter (AED) of 0.2 to 0.4 microns (Sehemel, 1978). The dry deposition velocity of 0.005 m/s is an approximate value for tritiated water vapor (Fallon, 1983; Sweet, 1984). The dry deposition velocity of 0.01 m/s is appropriate for unfiltered releases straight into environment and corresponds to particles with an AED between 2 to 5 microns (Sehemel, 1978).

Additional discussion on the topic is presented in Appendix A and in the NRC reference for recommended MACCS inputs (NRC, 1990b).

Dispersion Data Block (DP)

Variable YSCALE (Scaling factor for sigma y)

NUREG/CR-6613, Vol. 1 – page 5-14

Line within MACCS2 IN1A.INP sample file:

```
DPYSCALE001    1.
```

For a specific application:

Normally this value should not be changed. This value may be changed to calculate a dose from a release of up to 100 hours (the upper valid range of the model). The longer release duration correction factor is calculated by dividing the new duration in seconds by 180 seconds and raising the quotient to the 0.25 power. The release duration (variable PLUDUR in the RD data block) must be set equal to 180 seconds. If the user changes the 180-second basis, e.g. use of a new dispersion set with a ten-minute basis, then this must be reflected in the calculation.

Variable ZSCALE (Scaling factor for sigma z)

NUREG/CR-6613, Vol. 1 – page 5-18

Line within MACCS2 IN1A.INP sample file:

```
DPZSCALE001    1.27
```

For general application:

The calculation of this variable is discussed in Appendix A of this document under surface roughness, and is calculated as $(z_{new}/z_{ref})^{0.2}$, where the quotient of the new and reference surface roughness length is raised to the power of 0.2 Thus, the scaling factor as a function of surface roughness length , which approximately equals one-tenth of the height of roughness obstacles (Hanna, 2002), is

Obstacle Height	30 cm	100 cm	10 m
Surface Roughness Length	3 cm	10 cm	100 cm
σz correction	1.	1.27	2.02

The surface roughness parameter is region-of-transport specific and should be changed to be consistent for the environment surrounding facility in question.

Variables CYSIGA, CYSIGB, CZSIGA, and CZSIGB (Linear and Exponential Terms for sigma y and sigma z), specifies the dispersion parameter coefficients used.

NUREG/CR-6613, Vol. 1 – pages 5-10 to 5-12

These values should be set once for the dispersion parameter set being applied, such as shown below for the MACCS Tadmor-Gur set of fitting constants (NRC, 1990b):

```
DPCYSIGA001   0.3658   0.2751   0.2089   0.1474   0.1046   0.0722
DPCYSIGB001    .9031    .9031    .9031    .9031    .9031    .9031
DPCZSIGA001   2.5E-4   1.9E-3       .2       .3       .4       .2
DPCZSIGB001    2.125   1.6021     .8543    .6532    .6021    .6020
```

However, if an individual location has a specific set of linear and exponential terms for sigma y (σ_y) and sigma z (σ_z), then those values should be used. In MACCS2, dispersion coefficients are specified through either the curve-fit constant inputs as shown above or through tabular values as shown next. If the tabular values are used, the lines shown above for CYSIGA, CYSIGB, CZSIGA and CZSIGB are commented out.

Variable NUM_DIST, A-STB/DIS, B-STB/DIS, C-STB/DIS, D-STB/DIS, E-STB/DIS, and F-STB/DIS (Number of distances in dispersion look-up table and stability class data for each class)[5]

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Line within MACCS2 IN1A.INP sample file:

```
NUM_DIST001   50
A-STB/DIS01        1.000E+00     3.6580E-01     2.5000E-04  Tadmor/Gur (0.5-5 km)
A-STB/DIS02        1.400E+00     4.9569E-01     5.1105E-04  Tadmor/Gur (0.5-5 km)
A-STB/DIS03        2.000E+00     6.8408E-01     1.0905E-03  Tadmor/Gur (0.5-5 km)
  .
  .
  .
F-STB/DIS50        1.000E+07     1.5144E+05     3.2736E+03  Tadmor/Gur (0.5-5 km)
```

For a specific application:

These values should be set once and then not changed. Some sites and facility locations may have experimental data applicable over the region of transport. If this is the case, then fits to those data (sigma y and sigma z values) can be used.

---

[5] If the curve fits documented above are to be used for sigma y and sigma z, the NUM_DIST variable is set to zero and the lines for A-STB/DIS, B-STB/DIS, C-STB/DIS, D-STB/DIS, E-STB/DIS, and F-STB/DIS are commented out.

Alternatively, if experimental data are not available, then default data can be applied.

Plume Meander Data Block (PM)

Variable TIMBAS (Time base for the parameterization of the plume meander adjustment factor (seconds).)

NUREG/CR-6613, Vol. 1 – pages 5-18 to 5-19

Line within MACCS2 IN1A.INP sample file:

```
PMTIMBAS001    600.   (10 MINUTES)
```

For general application:

This value should be set once and not changed.

If the values based on the Project Prairie Grass are being used as given in the sample MACCS2 input, set the value to three minutes (180 s) (NRC, 1990b).

If another set of dispersion coefficients is being used, the value should be consistent with the time-basis of those experiments.

Plume Rise Data Block (PR)

NUREG/CR-6613, Vol. 1 – pages 5-20 to 5-21

Variable SCLCRW (Linear scaling factor on the critical wind speed used in determining if buoyant plumes will be trapped in building wake).

```
PRSCLCRW001   1.
```

Variable SCLADP (Linear scaling factor on the plume rise formula for unstable and neutral conditions (classes A – D)).

```
SCALING FACTOR FOR THE A-D STABILITY PLUME RISE FORMULA
(USED BY FUNCTION PLMRIS)
PRSCLADP001   1.
```

Variable SCLADP (Linear scaling factor on the plume rise formula for stable conditions (classes E and F)).

```
SCALING FACTOR FOR THE E-F STABILITY PLUME RISE FORMULA
(USED BY FUNCTION PLMRIS)
 PRSCLEFP001   1.
```

Wake Effects Data Block (WE)

Note: The building size may not be credited if a stack release is being modeled.

NUREG/CR-6613, Vol. 1 – pages 5-21 to 5-23

Variable SIGYINT (Initial sigma Y value)
Line within MACCS2 IN1A.INP sample file:

```
SIGYINIT001  9.302  9.302 (initial sigma-y, calculated for 40 meter wide bldg.)
```

For a specific application:
Normally this value should be set equal to its minimum value of 0.1 for each plume released. Thus no credit is taken for the size of the building. If the building is credited, the initial sigma y value should be calculated by dividing the average width of the building by 4.3 (Chanin, 1997).

Variable SIGZINT (Initial sigma Z value)
Line within MACCS2 IN1A.INP sample file:

```
SIGZINIT001  23.26  23.26 (initial sigma-z, calculated for 50 meter high bldg.)
```

For a specific application:
Normally this value should be set equal to its minimum value of 0.1 for each plume released. Thus no credit is taken for the size of the building. If the building is credited, the initial sigma y value should be calculated by dividing the height of the building by 2.15 (Chanin, 1997).

Variable BUILDH (Height of the building)
Line within MACCS2 IN1A.INP sample file:

```
WEBUILDH001   50.0  50.0  (Surry)
```

For a specific application:
Normally this value should be set equal to its minimum value of 1.0. The value is now solely used in MACCS2 to evaluate whether a buoyant plume is entrained in the turbulent wake of the facility.[6]

---

[6] In previous versions of MACCS, the building height input was also used to establish the initial value of σ_{z0} for the plume

Release Description Data Block (RD)

NOTE: All values in this data block may be modified using a change case.

NUREG/CR-6613, Vol. 1 – pages 5-23 to 5-29

Variable ATNAM2 (Source term identifier)

NUREG/CR-6613, Vol. 1 – page 5-24

Line within MACCS2 IN1A.INP sample file:

```
RDATNAM2001 'SECOND DRAFT 1150, WORST CASE SOURCE TERM FOR EARLY FATALITIES'
```

For a specific application:

Change the entire character string to identify the source term.

Note: A unique identifier must be used for each case

Variable NUMREL (Number of plume segments being released)

NUREG/CR-6613, Vol. 1 – page 5-24

Line within MACCS2 IN1A.INP sample file:

```
RDNUMREL001          2
```

For a specific application:

Change to the number (≤ 4) of plume segments defined in the source term. If more than four plume segments are defined, the activity of consecutive source terms may be added together if they have the same release duration, release height, and sensible heat rate. The release duration of the combined plume segments is the same as the individual plume segments.

Note:

For MACCS2 applications only, if FOUR plume segments are used then change cases should NOT be used for additional source terms as the results associated with the subsequent source terms will be wrong (see Appendix B). It is highly recommended that one to two plume segments only be used for DSA cases applying MACCS2.

Variable REFTIM (Representative time point for each plume)

NUREG/CR-6613, Vol. 1 – page 5-25

Line within MACCS2 IN1A.INP sample file:

```
RDREFTIM001       0.00       0.50
```

For a specific application:

The representative time point for each plume should be zero

Variable PLHEAT (Sensible heat rate of each plume segment)

NUREG/CR-6613, Vol. 1 – page 5-25

Line within MACCS2 IN1A.INP sample file:

```
RDPLHEAT001     3.7E+6     1.7E5
```

For a specific application:

If the sensible heat rate is credited and the release mechanism is an explosion, the energy of the event can be divided by sixty seconds, as a conservative reduction. This will underpredict the sensible heat rate of the event by at least an order of magnitude as explosions are normally much less than one minute in duration. Note: An alternative approach for modeling detonations with MACCS2, and a comparison to test data is documented by C. Steele, DOE/LAAO (Steele, 1998).

For most accident analysis fire types, the MACCS2 sensible energy option should be applied only for well-defined fires. Credit only sensible heat fraction for the thermal buoyancy effect, and apply conservative spatial factors to account for area-type fires. Assume shortest duration consistent with fire sequence definition.

Variable PLHITE (Release height of each plume segment)

NUREG/CR-6613, Vol. 1 – page 5-26

Line within MACCS2 IN1A.INP sample file:

```
RDPLHITE001         0.        0.
```

For a specific application:

If the release height is not defined in the given source term, this value should be set equal to zero meters for each plume segment. If the release is elevated and the release height is not at least 2.5 times the tallest collocated building height, the release height is set equal to zero.

Variable PLUDUR (Plume duration of each plume segment)

NUREG/CR-6613, Vol. 1 – page 5-26

Line within MACCS2 IN1A.INP sample file:

```
RDPLUDUR001      1800.    22000.
```

For a specific application:

If the release duration is not defined in the given source term, this value should be set equal to 180 seconds (or the value of TIMBAS defined in the expansion factor data block) for each plume segment. The value range on this parameter is the TIMBAS value (180 seconds) to 36000 seconds (10 hours). Release duration of longer than 10 hours are calculated by setting the duration of the plume segment to TIMBAS and applying the appropriate YSCALE factor. Note that in contrast to MACCS, where multiple plume segments were not allowed to overlap each other in time, MACCS2 allows the specification of overlapping plumes.

Variable PDELAY (Start time of each plume segment)

NUREG/CR-6613, Vol. 1 – page 5-26

Line within MACCS2 IN1A.INP sample file:

```
RDPDELAY001      3700.    10000.
```

For a specific application:

Specifies the start time of each plume segment in seconds from the time of accident initiation. Note that in contrast to MACCS, where multiple plume segments were not allowed to overlap each other in time, MACCS2 allows the specification of overlapping plumes

Variable PSDIST (Dry deposition velocity bin distribution)

NUREG/CR-6613, Vol. 1 – page 5-27

Line within MACCS2 IN1A.INP sample file:

```
RDPSDIST001      1.
RDPSDIST002      1.
RDPSDIST003      1.
RDPSDIST004      1.
RDPSDIST005      1.
RDPSDIST006      1.
RDPSDIST007      1.
RDPSDIST008      1.
RDPSDIST009      1.
```

For a specific application:

A dry deposition velocity distribution must be specified for each chemical group even if dry deposition is turned off for that group. The dry deposition bins were defined in variable VDEPOS. As discussed previously, a dry deposition velocity of 0.001 m/s is appropriate for filtered releases. Similarly, a dry deposition velocity of 0.005 m/s is an approximate value for tritiated water vapor. A dry deposition velocity of 0.01 m/s is appropriate for unfiltered releases into the environment.

Variable CORINV (Inventory available for release into the environment)

NUREG/CR-6613, Vol. 1 – page 5-27

Line within MACCS2 IN1A.INP sample file:

```
RDCORINV001     Co-58         3.223E+16
RDCORINV002     Co-60         2.465E+16
RDCORINV003     Kr-85         2.475E+16
  .
  .
  .
RDCORINV060     Cm-244        2.596E+15
```

For a specific application:

Enter the radionuclides and their associated inventories for the specific application. The radionuclides here do not need to be entered in the same order as provided in the default listing.

Variable CORSCA (Inventory scaling factor)

NUREG/CR-6613, Vol. 1 – page 5-28

Line within MACCS2 IN1A.INP sample file:

```
RDCORSCA001   0.715  *  SURRY
```

For a specific application:

This value is most often used to scale the inventory units of curies to the MACCS required value of becquerel (Bq). However, the value may be used to scale the inventory to meet any need.

Variable RELFRC (Fraction of inventory released in each plume segment)

NUREG/CR-6613, Vol. 1 – pages 5-28 – 5-29

Line within MACCS2 IN1A.INP sample file:

```
RDRELFRC001 1.0E+0 6.8E-1 6.4E-1 1.7E-1 4.2E-3 2.3E-3 1.6E-4 4.0E-4 6.3E-3
RDRELFRC002 4.3E-3 9.5E-3 2.4E-3 1.4E-1 6.8E-2 4.7E-4 6.8E-3 7.1E-3 5.4E-2
```

For a specific application:

A value must be specified for each chemical group and plume segments. The fraction of release is applied uniformly in to all radionuclides within a chemical group.

Variable APLFRC (Indicates whether the inventory of a daughter radionuclide is to be released with the release faction of the parent or the daughter)

NUREG/CR-6613, Vol. 1 – page 5-28

Line within MACCS2 IN1A.INP sample file:

```
RDAPLFRC001   PARENT      (apply rel fracs the same as prior versions)
```

For a specific application:

When the execution is being modeled to simulate a MACCS execution, this value should be set equal to "PARENT". In all other cases, the value should be set equal to "PROGENY".

Output Control Data Block (OC)

NUREG/CR-6613, Vol. 1 – pages 5-29 –5-31

Variable ENDAT1 (Flag for Ending Code Execution)

NUREG/CR-6613, Vol. 1 – page 5-29

Line within MACCS2 IN1A.INP sample file:

```
OCENDAT1001  .FALSE. (SET THIS VALUE TO .TRUE. TO SKIP EARLY AND CHRONC)
```

For a specific application:

Normally this value should not be changed. If the dilution factor (χ/Q) is the only consequence measure of interest, the execution should be stopped with ATMOS by setting the value to TRUE.

Variable IDEBUG (Debug Flag)

NUREG/CR-6613, Vol. 1 – pages 5-29 – 5-30

Line within MACCS2 IN1A.INP sample file:

```
OCIDEBUG001  0
```

For a specific application:

Normally this value should not be changed. However, the user may find it helpful to set the debug to a higher value – 1 or 2 for atmospheric transport results and 3 for hourly meteorological data for each trial. It is therefore useful for comparing MACCS2 results with hand calculations using the equations in the code documentation, or alternative code results.

Variable NUCOUT (Radionuclide to be listed on the dispersion listings)

NUREG/CR-6613, Vol. 1 – page 5-31

Line within MACCS2 IN1A.INP sample file:

```
*OCNUCOUT001  CS-137
```

For a specific application:

Normally this value should not be changed. However, when either intermediate results or MACCS2 atmospheric results are desired, this value should be set equal to the dominant radionuclide.

Variable NUM0 (Number of requested outputs)

NUREG/CR-6613, Vol. 1 – pages 5-40 –5-41

Line within MACCS2 IN1A.INP sample file:

```
TYPE0NUMBER      2
```

For a specific application:

Normally this value should be set equal to zero. However, when general atmospheric results or the dilution factor only is desired, this value should be set equal to the number of desired results

Variable INDREL and INDRAD (Plume segment index and spatial endpoint index for results)

NUREG/CR-6613, Vol. 1 – pages 5-41 - 42

Line within MACCS2 IN1A.INP sample file:

```
TYPE0OUT001      1        9
TYPE0OUT002      1       10         XCCDF
```

For a specific application:

Normally these lines should be commented out. However, when general atmospheric results or the dilution factor only is desired, these values will be changed to reflect the desired results. Additional lines may be needed.

Meteorological Sampling Data Block (M1)

Variable METCOD (Meteorological sampling specification)

NUREG/CR-6613, Vol. 1 – pages 5-31 to 5-32
Line within MACCS2 IN1A.INP sample file:

```
* METEOROLOGICAL SAMPLING DATA BLOCK
*
* METEOROLOGICAL SAMPLING OPTION CODE:
*
* METCOD = 1, USER SPECIFIED DAY AND HOUR IN THE YEAR (FROM MET FILE),
*          2, WEATHER CATEGORY BIN SAMPLING,
*          3, 120 HOURS OF WEATHER SPECIFIED ON THE ATMOS USER INPUT FILE,
*          4, CONSTANT MET (BOUNDARY WEATHER USED FROM THE START),
*          5, STRATIFIED RANDOM SAMPLES FOR EACH DAY OF THE YEAR.
*
M1METCOD001  2
```

For a specific application:
For DSA applications, weather category bin sampling (METCOD=2) or stratified random sampling (METCOD=5) is generally specified.

Boundary Weather Data Block (M2)

Note: The values in this data block must always be defined. When constant meteorological conditions are chosen (METCOD = 4), the input values represent the constant meteorological conditions. In all other cases, they represent the meteorological data if the plume has not traversed the entire grid in 120 hours.

Variable LIMSPA (Index of last radial endpoint for measured meteorological data)

NUREG/CR-6613, Vol. 1 – pages 5-32 – 5-33
Line within MACCS2 IN1A.INP sample file:

```
M2LIMSPA001  25
```

For a specific application:
This value should be set equal to the index of the last spatial interval

Variable BNDMXH (Boundary weather mixing layer height)

NUREG/CR-6613, Vol. 1 – page 5-33

Line within MACCS2 IN1A.INP sample file:

```
M2BNDMXH001  1000.  (METERS)
```

For a specific application:

This value should be set equal to the appropriate mixing height for the selected stability class.

Variable IBDSTB (Boundary weather stability class)

Line within MACCS2 IN1A.INP sample file:

NUREG/CR-6613, Vol. 1 – page 5-33

```
M2IBDSTB001  4      (D-STABILITY)
```

For a specific application:

This value should be set equal to the numeric index of the desired stability class.

Variable BNDRAN (Boundary weather rain rate)

NUREG/CR-6613, Vol. 1 – page 5-33

Line within MACCS2 IN1A.INP sample file:

```
M2BNRAND001  0.     (MILLIMETERS/HOUR)
```

Variable BNDWND (Boundary weather windspeed)

NUREG/CR-6613, Vol. 1 – page 5-34

Line within MACCS2 IN1A.INP sample file:

```
M2BNDWND001  5.     (M/S)
```

For a specific application:

This value should be set equal to the desired windspeed.

Fixed Start Time Data Block (M3)

Note: The values in this data block must be defined if METCOD does not equal 2 or 5.

Variable ISTRDY (Index of start day from meteorological data file)

NUREG/CR-6613, Vol. 1 – page 5-34

Line within MACCS2 IN1A.INP sample file:

```
M3ISTRDY001  157    (START TIME FOR PEAK ECONOMIC COST OF SAMPLE PROBLEM A)
```

For a specific application:
This line should not be changed.

Variable ISTRHR (Index of start hour from meteorological data file)

NUREG/CR-6613, Vol. 1 – page 5-34

Line within MACCS2 IN1A.INP sample file:

```
M3ISTRHR001  10     (START TIME FOR PEAK ECONOMIC COST OF SAMPLE PROBLEM A)
```

For a specific application:
This line should not be changed.

Meteorological Bin Sampling Data Block (M4)

Variable NSMPLS (Number of samples per bin)

NUREG/CR-6613, Vol. 1 – page 5-37

Line within MACCS2 IN1A.INP sample file:

```
M4NSMPLS001  4  (THIS NUMBER SHOULD BE SET TO 4 FOR RISK ASSESSMENT)
```

For a specific application:
This parameter defines the number of weather sequences to be chosen from each of the individual weather category bins with METCOD=2 (weather category bin sampling) or from each day of the year with METCOD=5 (random stratified sampling). The user's manual advises that this input should be at least 4 when METCOD=2 and a divisor of 24 (i.e., 1, 2, 3, 4, 6, 8, 12 or 24) when METCOD=5. More robust sampling is achieved with more samples, however,

more calculation time is required. Unless calculation time is a real concern, this value should be set equal once to maximum value of 24 and then not changed. With METCOD=5, setting the number of samples to 24 will result in MACCS sampling every hour of the year.

Variable IRSEED (Random Number Generator Seed)

NUREG/CR-6613, Vol. 1 – page 5-38

Line within MACCS2 IN1A.INP sample file:

```
M4IRSEED001   79
```

For a specific application:

This value should be selected based on the meteorological data associated with a specific location then not changed. This is done by selecting a set of representative base source terms, and then executing the code for each possible seed. From the resulting MOI TEDE values, the seed can be chosen.

See pages 5-39 and 5-40 of NUREG/CR-6613 for special inputs required for "User-Supplied Weather Sequence Data" and "CCDFs of Atmospheric Results", respectively.

4.5 EARLY INPUT FILE

Similar to the approach taken in Section 4.4 for ATMOS, the particular EARLY input file discussed in the following is used as a beginning baseline. It is one of the sample files (e.g., IN2A.INP) supplied with the MACCS2 software compact disc from RSICC. If a variable is not explicitly mentioned, it is not necessary to change its value in the file.

For each section of input, MACCS2 page-specific references are provided. These will allow the DOE safety analyst to review original reports from the SNL code developer to check on a specific variable.

Dose Conversion Factor File

Review pages 6-4 through 6-5 for options on the particular dose conversion factor file used in a given MACCS2 run.

Miscellaneous Data Block (MI)

NUREG/CR-6613, Vol. 1 – pages 6-6 to 6-9

Variable EANAM1 (EARLY input file identifier line)

Line within MACCS2 IN2A.INP sample file:

```
MIEANAM1001  ' IN2A.INP, MODIFIED 6/92, SURRY, SAMPLE PROBLEM A, EARLY INPUT'
```

For a specific application:
Change to a descriptive title for this execution of MACCS2

Variable IPLUME (Dispersion model option code)
Line within MACCS2 IN2A.INP sample file:

```
MIIPLUME001  2
```

For a specific application:

This value should be set once to 1 and then not changed.

Variable IPRINT (Debug Flag)
Line within MACCS2 IN2A.INP sample file:

```
MIIPRINT001  0
```

For a specific application:
Normally this value should not be changed. However, the novice user will find it helpful to set the debug to a higher value and compare the MACCS2 results with hand calculations using the equations in the code documentation.

Variable RISCAT (Logical flag for consequences by contribution to mean)
Line within MACCS2 IN2A.INP sample file:

```
MIRISCAT001   .FALSE.
```

For a specific application:
Normally this value should not be changed. However, the novice use will find it helpful to set the value to ".TRUE." and compare the MACCS2 results with hand calculations using the equations in the code documentation.

Variable OVRRID (Logical flag for overriding the code calculated windrose)
Line within MACCS2 IN2A.INP sample file:

```
MIOVRRID001  .FALSE.  (USE THE WIND ROSE CALCULATED FOR EACH WEATHER BIN)
```

For a specific application:

Normally this value should not be changed. However, if this value should be set equal to ".TRUE.", then the user-calculated windrose is inputted using the WINROS parameter that is described next.

Variable WINROS (probabilities of the wind blowing from the site into each of the 16 compass sectors (rotating clockwise from N to NNW when OVRRID parameter is set equal to ".TRUE.")

For a specific application:

Normally this parameter is not used in DSA applications.

Variable DCF_FILE (Name and location of the dose conversion factor file)

NUREG/CR-6613, Vol. 1 – page 6-5

Line within MACCS2 IN2A.INP sample file:

```
DCF_FILE001 'DOSDATA.INP'  (DCF file of MACCS 1.5.11.1)
```

For a specific application:

This value should be set once to the name and location of the dose conversion factor file and then not changed. For safety basis documents, the dose conversion factors from external radiation should be based on FGR 12, while those from internal radiation can be based on FGR 11 or preferably on the newer ICRP 68 or 72 recommendations. However, use of the ICRP 68/72 DCFs should be authorized by the local or cognizant DOE office.

Population Distribution Data Block (PD)

NUREG/CR-6613, Vol. 1 – pages 6-9 to 6-10

Variable POPFLG (Flag indicating whether a population file of uniform population is being used)

Line within MACCS2 IN2A.INP sample file:

```
PDPOPFLG001  FILE
```

For a specific application:

This value should be changed once to "UNIFORM" and then not changed

Variable IBEGIN (Index of radial endpoint where the population begins)

Line within MACCS2 IN2A.INP sample file:

```
*PDIBEGIN001  1   (SPATIAL INTERVAL AT WHICH POPULATION BEGINS)
```

For a specific application:
This line should be changed once by removing the comment indicator (the asterisk) from the beginning of the line.

Variable POPDEN (Uniform population density of the region)
Line within MACCS2 IN2A.INP sample file:

```
*PDPOPDEN001  50. (POPULATION DENSITY (PEOPLE PER SQUARE KILOMETER))
```

For a specific application:
This line should be changed once by removing the comment indicator (the asterisk) from the beginning of the line, and the value changed to zero. After the line has been changed once, it will not need to be changed again.

Organ Definition Data Block (OD)

NUREG/CR-6613, Vol. 1 – pages 6-10 to 6-12

Variable NUMORG (Number of organs to be considered)
Line within MACCS2 IN2A.INP sample file:

```
ODNUMORG001   10
```

For a specific application:
With the recommendation given in this document to use the dose conversion file that is generated from the FGRDCF code (Young, 1998) supplied with the MACCS2 code, the above line may be commented out. See item below for additional discussion.

Variable ORGDEF (List of organ names and flag to specify whether or not the organ is to be considered in the calculations)
Line within MACCS2 IN2A.INP sample file:

```
*
*             ORGNAM         ORGFLG
*
MIORGDEF001  'A-SKIN'        .TRUE.
MIORGDEF002  'A-RED MARR'    .TRUE.
MIORGDEF003  'A-LUNGS'       .TRUE.
MIORGDEF004  'A-THYROIDH'    .TRUE.
MIORGDEF005  'A-STOMACH'     .TRUE.
MIORGDEF006  'A-LOWER LI'    .FALSE.  (does not contribute to early fatalities)
MIORGDEF007  'L-EDEWBODY'    .TRUE.
MIORGDEF008  'L-RED MARR'    .TRUE.
```

```
MIORGDEF009  'L-BONE SUR'    .TRUE.
MIORGDEF010  'L-BREAST'      .TRUE.
MIORGDEF011  'L-LUNGS'       .TRUE.
MIORGDEF012  'L-THYROID'     .TRUE.
MIORGDEF013  'L-LOWER LI'    .TRUE.
MIORGDEF014  'L-BLAD WAL'    .TRUE.
MIORGDEF015  'L-LIVER'       .FALSE.
MIORGDEF016  'L-THYROIDH'    .TRUE.
```

For a specific application:

With the recommendation given in this document to use the dose conversion file that is generated from the FGRDCF code (Young, 1998) supplied with the MACCS2 code, the above lines may be commented out. The FGRDCF-based dose conversion file provides inhalation and ingestion DCFs from FGR 11 and cloudshhine and groundshine dose coefficients from FGR 12. Recall that FGR 11 inhalation DCFs are based on weighting factors from ICRP 26 (ICRP, 1977) and organ/tissue models documented in ICRP 30 and 48 (ICRP, 1979a to 1982c, and ICRP, 1986). With the local or cognizant DOE office's approval, the inhalation and ingestion DCFs can be replaced with those from ICRP 68 or 72.

NOTE: The dose conversion file that is created by the FGRDCF code creates a two-line header with the letter string "FGRDCF" embedded within the first header line. MACCS2 checks for the letter string "FGRDCF" within the first seven letters of the first header line and if found, assumes that the dose conversion file was generated from the FGRDCF code and sets the lists of available organs to be consistent with the FGRDCF code and with FGR 11 and 12. Note that MACCS2 adds a prefix of "L-" to the organ names that is used to indicate a 50-year committed dose. Specifically, the list of organs is as follows:

- L-GONADS
- L-BREAST
- L-LUNGS
- L-RED MARR
- L-BONE SUR
- L-THYROID
- L-REMAINDER
- L-EFFECTIVE
- L-SKIN(FGR)

Shielding and Exposure Data Block (SE)

NUREG/CR-6613, Vol. 1 – pages 6-12 to 6-14

Variable CSFACT (Cloudshine shielding factor)
Line within MACCS2 IN2A.INP sample file:

```
SECSFACT001      1.     0.75     0.6   *  SURRY SHELTERING VALUE
```

For a specific application:

The cloudshine shielding factor for all three activity levels should be set equal to one and then not changed.

Variable PROTIN (Inhalation protection factor)
Line within MACCS2 IN2A.INP sample file:

```
SEPROTIN001      1.     0.41      0.33  * VALUES FOR NORMAL ACTIVITY AND
```

For a specific application:

The inhalation protection factor for all three activity levels should be set equal to one and then not changed.

Variable SKPFAC (Skin absorption protection factor)
Line within MACCS2 IN2A.INP sample file:

```
SESKPFAC001  1.0      0.41     0.33    * VALUES FOR NORMAL ACTIVITY AND
```

For a specific application:

The skin absorption protection factor for all three activity levels should be set equal to one and then not changed.

Variable GSHFAC (Groundshine shielding factor)
Line within MACCS2 IN2A.INP sample file:

```
SEGSHFAC001      0.5    0.33    0.2   * VALUE FOR NORMAL ACTIVITY SELECTED BY
```

For a specific application:

The groundshine shielding factor for all three activity levels should be set equal to one and then not changed.

Variable BRRATE (Breathing rate)
Line within MACCS2 IN2A.INP sample file:

```
SEBRRATE001  2.66E-4  2.66E-4  2.66E-4
```

For a specific application:

The breathing rate for all three activity levels should be set equal to 3.33E-04 m^3/s (DOE, 1998), as discussed in Appendix A. Note that the basis for DOE-STD-1027-92 hazard categorization is slighter higher at 3.47E-04 m^3/s.

Variable RESCON (Resuspension inhalation model concentration coefficient)
Line within MACCS2 IN2A.INP sample file:

```
SERESCON001   1.E-4     (RESUSPENSION IS TURNED ON)
```

For a specific application:

This value should be set once and not changed. Per DOE-3009-94 Appendix A, resuspension does not need to be included in the DSA calculations of TEDE. If resuspension is to be turned off, set the value equal to zero. If resuspension is to be applied, this value does not need to be changed.

Evacuation Zone Data Block (EZ)

NUREG/CR-6613, Vol. 1 – pages 6-14 to 6-29

Variable LASMOV (Index of last radial ring involved in the evacuation)
Line within MACCS2 IN2A.INP sample file:

```
EZLASMOV001     15    (EVACUEES DISAPPEAR AFTER TRAVELING TO 20 MILES)
```

For a specific application:

This value should be set once to zero and then not changed.

Shelter and Relocation Data Block (SR)

Variable ENDEMP (Duration of the emergency phase)

NUREG/CR-6613, Vol. 1 – page 6-27

Line within MACCS2 IN2A.INP sample file:

```
SRENDEMP001  604800.   (ONE WEEK)
```

For a specific application:

This value should be set once to 86400 (24 hours) and then not changed. This is the minimum value allowed by MACCS2 and represent conservative implementation of the prescribed exposure duration of 2 hours (or 8 hours for slow-developing release scenarios) (DOE, 1994).

Variable TIMHOT (Time for hot-spot relocation)
Line within MACCS2 IN2A.INP sample file:

```
SRTIMHOT001  43200.    (ONE-HALF DAY)
```

For a specific application:

This value should be set once to 86400 (24 hours) and then not changed.

Early Fatality Data Block (EF)

NUREG/CR-6613, Vol. 1 – pages 6-29 to 6-33

Variable NUMEFA (Number of early fatality effects)
Line within MACCS2 IN2A.INP sample file:

```
EFNUMEFA001   3
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Early Injury Data Block (EI)

NUREG/CR-6613, Vol. 1 – pages 6-33 to 6-35

Variable NUMEIN (Number of early injury effects)
Line within MACCS2 IN2A.INP sample file:

```
EINUMEIN001  7
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Latent Cancer Data Block (LC)

NUREG/CR-6613, Vol. 1 – pages 6-35 to 6-40

Variable NUMACA (Number of acute exposure cancer effects)

Line within MACCS2 IN2A.INP sample file:

```
LCNUMACA001   7
```

For a specific application:

Normally, this value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type One Output - Health Effects Data Block (T1)

Variable NUM1 (Number of requested outputs)

NUREG/CR-6613, Vol. 1 – page 6-43

Line within MACCS2 IN2A.INP sample file:

```
TYPE1NUMBER    27
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type Two Output – Early Fatality Radius Data Block (T2)

Variable NUM2 (Number of requested outputs)

NUREG/CR-6613, Vol. 1 – page 6-45

Line within MACCS2 IN2A.INP sample file:

```
TYPE2NUMBER  1
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type Three Output – Population Exceed Dose Threshold Data Block (T3)

Variable NUM3 (Number of requested outputs)

NUREG/CR-6613, Vol. 1 – page 6-46

Line within MACCS2 IN2A.INP sample file:

```
TYPE3NUMBER  3
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type Four Output – Average Individual Risk Data Block (T4

NUREG/CR-6613, Vol. 1 – pag 6-47 to 6-48

Variable NUM4 (Number of requested outputs)
Line within MACCS2 IN2A.INP sample file:

```
TYPE4NUMBER  5
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type Five Output – Population Dose Data Block (T5)

Variable NUM5 (Number of requested outputs)

NUREG/CR-6613, Vol. 1 – pages 6-48 to 6-49

Line within MACCS2 IN2A.INP sample file:

```
TYPE5NUMBER     3
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type Six Output – Centerline Dose at Distance Data Block (T6)

Variable NUM6 (Number of requested outputs)

NUREG/CR-6613, Vol. 1 – pages 6-49 to 6-52

Line within MACCS2 IN2A.INP sample file:

```
TYPE6NUMBER     0
```

The output of interest for DSA applications is the Type Number 6 output, which signifies centerline doses at a distance. Refer to Section 7 for obtaining this result at specified distances. ***The result of interest for DSA applications is the 95th percentile direction-independent dose, and is specified as a type 6 result***.

Variable ORGNAM, PATHNM, I1DIS6, and I2DIS6 (Organ name, pathway name, inner spatial interval, and outer spatial interval as input by OUT)

Line within MACCS2 IN2A.INP sample file:

```
*TYPE6OUT001  'RED MARR'    'TOT ACU'      1       19     (0-50 MILES)
*TYPE6OUT002  'LUNGS'       'TOT ACU'      1       19     (0-50 MILES)
*TYPE6OUT003  'EDEWBODY'    'TOT LIF'      1       26     (0-1000 MILES)
```

For a specific application:

The comment indicator (the asterisk) should be removed from the output definition. The organ name should be change to “L-EFFECTIVE”. The pathway name should be changed to “TOT LIF”. The inner and outer spatial intervals (radii) should be set equal to the ring encompassing the receptor location. If the release is elevated or heated and the MOI is located within several kilometers of the release location, the MOI may not be located at the closest site boundary but at the point of plume touch down. In this case, the inner and outer spatial intervals should be reset to encompass the location of the plume touch down.

Type Seven Output – Centerline Risk vs. Distance Data Block (T7)

Variable NUM7 (Number of requested outputs)

NUREG/CR-6613, Vol. 1 – pages 6-52 to 6-54

Line within MACCS2 IN2A.INP sample file:

```
TYPE7NUMBER     0
```

For a specific application:

This value should not be changed.

Type Eight Output – Population Weighted Risk Data Block (T8)

Variable NUM8 (Number of requested outputs)

$\boxed{\text{NUREG/CR-6613, Vol. 1 – pages 6-54 to 6-55}}$

Line within MACCS2 IN2A.INP sample file:

```
TYPE8NUMBER   2
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type A Output – Peak Dose at a Distance Data Block (TA)

Variable NUMA (Number of requested outputs)

$\boxed{\text{NUREG/CR-6613, Vol. 1 – pages 6-56 to 6-57}}$

Line within MACCS2 IN2A.INP sample file:

```
TYPE8NUMBER   1
```

For a specific application:

Normally, this value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type B Output – Peak Dose at a Distance and Sector Data Block (TB)

Variable NUMA (Number of requested outputs)

$\boxed{\text{NUREG/CR-6613, Vol. 1 – pages 6-57 to 6-58}}$

Line within MACCS2 IN2A.INP sample file:

```
TYPEBNUMBER   0
```

For a specific application:

Normally, this value should not changed.

4.6 DOSE CONVERSION FACTOR FILE

For safety basis documentation, the FGRDCF code (Young, 1998) supplied with the MACCS2 code may be used to create a dose conversion factor file for either MACCS or MACCS2 execution. The inhalation and ingestion dose conversion factors should be replaced with those from ICRP 68 or 72. As noted previously, use of the newer DCF files should be based on the local or cognizant DOE office's approval.

Note that if the source term includes tritium oxide, its 50-year committed inhalation dose conversion factor should be increased by 50% to include the effects of skin absorption as directed by International Commission on Radiological Protection (ICRP) in their publication 30 (ICRP, 1978).

4.7 Radiological Dispersion and Consequence Analysis Recommendation

Recommendations on inputs for MACCS2 modeling radiological dispersion and consequences and their bases, discussed at length in Appendix A, are summarized in Table 4-1. In most cases, the standard practices and recommendations are site-independent.

Table 4-1. Standard Practices and Assumptions Recommended for DSA Dispersion and Consequence Analysis

MODEL/ATTRIBUTE	Recommendation/Basis
Model Basis	Gaussian plume or puff model; DOE-STD-3009-94, CN2, Appendix A
Receptor Distances & Meteorology	• MOI: Evaluate using or conservative to 95th percentile methodology per DOE-STD-3009-94, CN2, Appendix A and NRC Regulatory Guide 1.145; • Evaluate at touchdown point for elevated or sensible energy-buoyant releases
Default Meteorological Conditions	• Prescriptive: F and low windspeed (1 - 1.5 m/s) for offsite; • D and intermediate windspeed (~4.5 m/s) for onsite receptors;
Dispersion Parameters	▪ >100 meters from source: Site tracer gas parameterization; Pasquill-Gifford; Tadmor-Gur (Dobbins, 1979); Briggs (Hanna, 1982) • < 100 meters, use Eimutis and Konicek (1972), or other as justified
Mixing Layer Height	Apply local site/laboratory recommendations for seasonal and time-of-day estimates for the mixing layer height.
Surface Roughness	Adjust σ_z based on site features with AMS (1977) model
Release Duration	Should be consistent with accident analysis, and set of applicable dispersion parameters (σ_y). Scale to longer release duration by applying Gifford, or similar model. As a default conservatism, apply dispersion parameter set equal to or less than release duration.
Exposure	Two hours: DOE-STD-3009-94, CN2, App. A; RG 1.145 (to MOI) Sequences that take longer to develop; No longer than eight hours; DOE-STD-3009-94, CN2, App. A
Deposition	Dry deposition: Assume the deposition velocity is 1 cm/s for all unfiltered, non-tritium, non-noble gas species. If filtration is assumed in the scenario, apply the 0.1 cm/s deposition velocity. Tritium species deplete from airborne plumes as a function of the site environment. Recommendations have been documented indicating a range of 0.04 cm/s to 0.05 cm/s for tritium gas (HT), and 0.4 cm/s to 0.8 cm/s for tritiated water vapor (HTO). Wet deposition: Not used.
Dose Conversion Factors	1. ICRP-60 for biokinetic model and ICRP-68/72 for dose coefficients 2. ICRP-26 for metabolic model; ICRP 30/48-based:DOE/EH-0070 and 0071; or Federal Guidance Reports 11 and 12
Pathways	Primary: Inhalation; DOE-STD-3009-94, CN2, Appendix A Secondary: Cloudshine, Groundshine (Important only for criticality source terms in non-reactor applications);

Table 4-1. Standard Practices and Assumptions Recommended for DSA Dispersion and Consequence Analysis (continued)

Breathing Rate	3.33E-04 m^3/s; DOE (1998); 3.47E-04 m^3/s; DOE-STD-1027-92.
Dose Commitment	50-year, per definition of TEDE in DOE-STD-3009-94, CN2, Appendix A
Evaluation Criterion	Offsite/MOI Evaluation Guideline - 25 rem; DOE-STD-3009-94, CN2, Appendix A
Terrain	Flat Earth acceptable for most near-field and MOI estimates; Terrain realistic for other site areas and offsite calculations (valley, land/water interface, and/or mountainous terrain)
Sensible heat in plume	1. The conservative assumption is to not credit plume rise due to fire or explosive release, apply a short duration, and assume ground-level release. 2. If the fire is "well-defined" and the release of sensible heat (and radionuclides) and the certainty of release from one location (i.e. approximates point source) is high, then current model in MACCS is adequate. 3. If the fire being modeled is out-of-facility, without intervening structures, and the sensible heat fraction is known, then for: (a.) pool fires – MACCS model should not be applied as is, but some initial plume conditions can be adjusted to estimate the thermal buoyancy effect; (b.) spatially localized fire – MACCS model is adequate. 4. For primarily indoor fires, the fraction of heat radiated to walls and ceilings may be uncertain, and interpretation of the results from a MACCS model would be uncertain.
Protective Actions	None; Conservatively assume no shielding by any structure or cut-off of ventilation (sheltering), or movement to avoid plume (evacuation)
Meteorological Sampling	Latin Hypercube Sampling of meteorological bins (categories of stability, windspeed); four or more samples are recommended if METCOD=2 in MACCS2. Alternatively, Stratified Random Sampling – draw samples from each time interval (~day) of the year. Twenty-four samples are recommended for MACCS2 if METCOD=5. At least one year of representative, qualified, hourly data;
Meteorological Data	At least one year of representative, qualified, hourly data; Two to five years is recommended (Regulatory Guide 1.23; Draft Regulatory Guide 1.11)

5.0 SPECIAL CONDITIONS FOR USE

The MACCS/MACCS2 codes have additional capabilities that generally are not used in standard DSA applications. For example, food ingestion doses can be calculated, but these results are not part of the DOE 3009 Appendix A requirement for safety basis dose calculations. Also, MACCS/MACCS2 has models to calculate population doses and show the relative benefits of evacuation and sheltering (as well as interdiction when food ingestion is considered), but results of this type also are not needed for safety basis dose calculations.

6.1 SOFTWARE LIMITATIONS

This section summarizes MACCS (6.1) and MACCS2 (6.2) software limitations in terms of past occurrences of errors and defects in various versions of the code. The last section (6.3) will be completed in the future as results of the gap analysis (comparison of MACCS2 with defined software standards) are made available.

6.2 MACCS Issues

During the use of MACCS 1.5.11 by different organizations for various reactor and non-reactor applications,[7] errors were discovered in the code. These errors prompted the issuance of a maintenance version of the MACCS code (i.e. version 1.5.11.1). The changes in the original MACCS source code were independently verified (Chanin, 1993) before the new source code (MACCS, Version 1.5.11.1) was released in 1993. In addition to the correction of errors in the original MACCS code, the MACCS, Version 1.5.11.1 distribution package included executables for several operating systems in addition to the original VAX/VMS system.

Although the aforementioned changes had a small impact on the results, the maintenance version of MACCS has an additional cancer fatality model. The older model is a linear quadratic equation based on BEIR III cancer model. The newer model is a discontinuous linear equation, based on review of the BEIR V cancer models in a report (LMF-132) prepared by the Lovelace Inhalation and Toxicology Research Institute (ITRI) (Chanin, 1993).

Since the issuance of the maintenance version of MACCS, several errors have been catalogued. The errors and additional enhancements have been corrected in MACCS2 (RSICC, 1997). Table 6-1 lists enhancements and corrections. It should be pointed out that except in one case, groundshine from criticality source terms (item #5), there is no impact to dose calculations performed in support of DSA from these modifications.

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[7] - The MACCS code is used for PSA studies and facility licensing throughout the United States and abroad by both commercial and government organizations

Table 6-1. Code Modifications to MACCS2 and Impact to DSA Calculation (See Pages 3-9 through 3-16 of RSICC (1997))

Error/Enhancement	Action	Impact to DSA MOI Dose Analysis
1. Dose-Dependent Reduction Factor Implementation Error	Corrected EARLY module for error to cancer risk estimates. Did not affect chronic, cancer risk calculations.	Cancer risks are not calculated for DSAs – No Impact
2. Number of People Exceeding Dose Threshold - Incorrect calculations when ten results are requested for the number of people exceeding a dose threshold - Inability to Report Small Values of Dose Threshold	- Subject coding error has been corrected in MACCS2 - MACCS2 has automatic switch to exponential format (from fixed) to allow reporting of dose thresholds < 0.0005 Sv (50 mrem)	This type of result is not calculated for DSAs – No Impact
3. Incomplete Implementation of the Intermediate Phase - health effects and collective doses - lack of interaction between intermediate phase relocation and farm interdiction	Corrections made in MACCS2 only: - Corrected dose data stored for intermediate phase - Mitigative actions are based upon intermediate phase results.	Intermediate and long-term phases are not calculated for DSAs – No Impact
4. Summation of Early and Intermediate Phase Costs	MACCS2 improved to report emergency and intermediate phase costs due to evacuation and relocation separately	Evacuation and relocation costs are not considered in DSAs – No Impact
5. Dose Calculations for Groundshine Following Plume Passage	Groundshine following plume passage was calculated by interpolating and extrapolating doses based on 8-hour and 1-week DCFs (MACCS). MACCS2 performs exact numerical integration.	Potentially important for criticality (short half-life radionuclides), but groundshine dose component is usually small – Minor Impact

Table 6-1. Code Modifications to MACCS2 and Impact to DSA Calculation (Continued)

Error/Enhancement	Action	Impact to DSA MOI Dose Analysis
6. Nonprintable characters in site data file and FORTRAN Source Code	MACCS query of population counts and other information in site data file may lead to code crash due to suspected nonprintable ASCII characters or control codes in the file. MACCS2 has eliminated this factor.	Does not affect MACCS non debugging runs – No Impact to DSA calculations
7. Minor Changes to Input and Output	MACCS2 improved to allow: - 99.9th quantile changed to show 99.5 quantile per NRC Reg. Guide 1.145 Variable DLBCST in CHRONC no longer allowed to have $0 cost for decontamination	Useful for some DSA calculations, but most DSA results will focus on 95th percentile, direction independent results. The decontamination factor cost issue is not applicable to DSA calculations. - No Impact Overall.

6.2 MACCS2 Issues

A Sandia National Laboratories SQA program was implemented in 1992. The SNL guidelines[8] (SNL, 1987; SNL, 1995; SNL, 1986; SNL, 1992; and SNL, 1989) followed the methodology established by IEEE software standards (IEEE, 1984). Of the five primary SNL software guideline volumes, two[9] were published after the completion of the original MACCS code. These documents demonstrate the development of the code was performed in a systematic way with each step thoroughly reviewed before the next step was taken. The other three volumes[10] were published during the development phase of the MACCS code and were in place before the beginning of the MACCS2 development. Although the guidelines were published after the completion of the MACCS code, the MACCS development followed a systematic method as did error reporting and correction processes associated with the code.

In the initial code development for MACCS2 the same systematic process was followed. A project plan was prepared as were draft versions of a development plan for the food model and for the inclusion of the new dose conversion factors. In addition, a draft test plan was developed. The draft test plan was followed through MACCS2 Version 1.02. However, the plans were never finalized and a formal SQA plan was not put into place.

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[8] - The SNL documentation is clearly described as guidance. The management directing the project may choose not to follow any part, or all, of the recommendations outlined in the guidelines.

[9] - The two volumes published after the beginning of the MACCS2 development were the Documentation volume and the Configuration Management volume. The Documentation volume (SNL, 1995) presents a description of documents needed for developing, maintaining, and defining software projects. The Configuration Management volume (SNL, 1992) presents a discussion of configuration management objectives and approaches throughout the software live cycle for software projects at SNL.

[10] - The three volumes published before the beginning of the MACCS2 development were Software Quality Planning volume, Standards, Practices, and Conventions volume, and Tools, Techniques, and Methodologies volume. The Software Quality Planning volume (SNL, 1987) presents an overview of procedures designed to ensure software quality. The Standards, Practices, and Conventions volume (SNL, 1986) presents standards and practices for developing and maintaining quality software at SNL and includes a description of the documents needed for a complete SQA package at SNL. The Tools, Techniques, and Methodologies volume (SNL, 1989) presents evaluations and a directory of software tools and methodologies available to SNL personnel.

In addition to early testing of the MACCS2 code by in-house staff, SNL contracted the University of New Mexico (UNM) to independently test the code during development. This testing was published in a draft document (Summa, 1996). The report focused on the following areas:

ATMOS Module: Calculation of the downwind relative air concentration (χ/Q) and of the diffusion parameters by using both the power law and the new look-up table methods

EARLY Module: Calculation of the acute thyroid dose, of the network evacuation centerline dose, of the radial evacuation peak dose, of the crosswind evacuation dose, and the dose when the evacuation speed changes

CHRONC Module: Testing of the ability to turn off the long-term phase and the decontamination model, comparison of intermediate phase and long-term phase doses, and calculation of the intermediate phase dose

The testing by UMN was done in an iterative manner. Errors discovered by UNM resulted in coding changes and a new version of the code. The new code version would then be retested by UNM for the function in question. This process would continue until the function worked correctly. The UNM testing did not include any of the preprocessors developed by SNL nor did it include the COMIDA food model developed at INEEL.

After the MACCS2 code was released, several new features of the MACCS2 code were verified against hand calculations at SRS (East 1997). These features were the calculation of the CCDF for the atmospheric concentration, and the vertical and horizontal diffusion parameters in the ATMOS module and the reporting of the peak dose both independent and dependent of sector in the EARLY module. The module functions tested worked properly.

As part of the MACCS2 SQA program evaluation, a review of the code's documentation and source code was performed. From that review, a number of undocumented changes from MACCS to MACCS2 were found. Many of the changes were simply a change in the upper and/or lower bound of the input parameter. Many of those input parameter changes can be attributed to the UNM testing effort. However, that effort was never published.

After the MACCS2 code had been released to the Radiation Safety Information Computation Center (RSICC) at Oak Ridge for distribution, an error was found during routine calculations at the DOE Pantex Plant. This error involved the source term looping function that produced erroneous results when four release plumes were specified. The coding error was introduced when the total number of radionuclides was increased from 825 to 900.[11] When this coding

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[11] This is the number of available radionuclides in the Dose Conversion Factor database. MACCS2, is still limited to 150 radionuclides per execution.

change was made, the dimensions of the variables associated with this change were properly increased, but the variables that were dependent on the changed variables were not modified. This led to a corruption of the data stored during each run and led to the subsequent erroneous results. See Appendix B for the Software Defect Notification.

With calculations made before upgrades to MACCS2 are completed, including corrections to the source term looping function, the user is advised to limit the number of plume segments to one to three. The SNL developers have reported at least one other error (also described in Appendix B). However, the emergency preparedness option is not used in obtaining MOI dose estimates, and thus is deemed of no impact to DSA calculations.

In the interim before the completion of the MACCS2 backfit package, safety analysts using MACCS2 Version 1.12 should proceed with caution, using the guidance contained herein (Section 4). Alternatively, MACCS Version 1.5.11.1 can be applied with the appropriate dose conversion factor data, using the guidance provided in Appendix D of this report.

In either case, independent confirmation and peer review of technical products is advised. “Spot checks” of key consequence calculations using an independent code calculation, or a set of spreadsheet or hand calculations, can frequently minimize or remove code result uncertainty.

6.3 Outcome of Gap Analysis

To be added at a later date after the completion of the gap analysis.

7.0 SAMPLE CALCULATIONS

This section contains an overview of the MACCS2 input files and output for a sample calculation of a ground-level release of 1 curie of Pu-239. Four cases were run to model the following types of release:

- Non-buoyant (base case)
- Non-buoyant plume with building wake
- Buoyant plume
- Buoyant plume with building wake

Random stratified sampling was used with the number of samples set to 24 to sample each hour of the day (for 365 days) from the meteorological data file.

The next two sections summarize key features of the ATMOS and EARLY input files. Four separate ATMOS files were used to model the four release cases. Graphical results from the four cases are shown next. Finally, the output listing for the base case is given.

The main objective of this section is to provide sample input files that illustrate the guidance in this report and to show examples of the types of output that MACCS2 can provide.

7.1 ATMOS Input Overview

The ATMOS module uses two input files. These files contain the input data needed for the ATMOS module (A5_BASE.INP) and a yearly meteorological data file which contains 365 days of meteorological conditions (METDATA.INP).

The following are the major assumptions associated with this analysis:

- The radial ring endpoints are at 0.1, 0.2, 0.3, 0.4, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, and 10.0 km.

- The base case is assumed to be an open-area release (no buildings in the vicinity) so the initial vertical and horizontal dispersion coefficients are each set to the minimum value of 0.1. Also, the building height is set to its minimum value of 1.0.

  In the building wake cases, the building is assumed to have a height (H_b) of 42.5 ft (13 m) and width (W_b) of 296 ft (90 m). The initial horizontal dispersion coefficient is set to 21 m (W_b/4.3) and the initial vertical dispersion coefficient is set to 6 m (H_b/2.15).

- The base case is assumed to a non-buoyant plume so the sensible heat rate is specified to be zero.

For the buoyant plume releases, the sensible heat rate is assumed to be 5 MW.

- One curie of Pu-239 is released over a ten-minute period.
- The inventory scaling factor (CORSCA) has been set equal to 3.7×10^{10} to convert the inventory units from curies to becquerels
- No wet deposition is assumed
- The dry deposition velocity is assumed to be 0.01 m/s, which corresponds to a particle with an aerodynamic equivalent diameter of 2 to 4 microns (Sehemel, 1978).
- The surface roughness length is specified as 10 cm to minimally credit the urban attributes of the operational area of the region of transport. MACCS (Jow, 1990) incorporates the change in the surface roughness using the model proposed in (AMS, 1977). In this model, the sigma z parameter is adjusted by applying the one-fifth law to the quotient of the new surface roughness divided by the Prairie Grass surface roughness (3 cm) (Haugen, 1959)

The site meteorological data files are composed of hourly data for a specific calendar year of qualified data, at a measured wind speed height of 10 meters.

7.2 EARLY Input Overview

The EARLY module uses two different input files, the file that contains the input data needed for the EARLY module (E1_TEDE.INP) and the dose conversion factor file (FGR_PU.INP).

The following are the major assumptions associated with this analysis:

- The assumed breathing rate is 3.33×10^{-4} cubic meters per second which is the DOE occupational breathing rate (DOE, 1998)
- A uniform population distribution of 0.0 people per square kilometer is assumed
- No shielding is assumed
- No evacuation and/or sheltering is assumed
- Results of interest are the centerline TEDE for all intervals

The last file needed by the EARLY module is the dose conversion factor file. The values within this file were generated with the FGRDCF code and are based on Federal Guidance Reports 11 and 12. (Eckerman, 1988 and Eckerman, 1993)

```
FGRDCF 06/18/02   12:22:20   BETA-TEST VERSION 1.10, MINOR FORTRAN FIXES 5/4/95
IMPLICIT DAUGHTER HALFLIVES (M) LESS THAN  90 AND LESS THAN 0.100 OF PARENT
         9 ORGANS DEFINED IN THE FILE:
GONADS
BREAST
LUNGS
RED MARR
BONE SUR
THYROID
REMAINDER
EFFECTIVE
SKIN(FGR)
         4 NUCLIDES DEFINED IN THE FILE:
Pu-238    W
Pu-239    W
Pu-240    W
Pu-241    W
          CLOUDSHINE  GROUND    GROUND    GROUND    INHALED   INHALED  INGESTION
                     SHINE 8HR SHINE 7DAY SHINE RATE ACUTE    CHRONIC
Pu-238
GONADS     6.560E-18 4.291E-14 9.011E-13 1.490E-18-1.000E+00 2.800E-05 2.330E-07
BREAST     1.270E-17 5.558E-14 1.167E-12 1.930E-18-1.000E+00 1.000E-09 8.410E-12
LUNGS      1.060E-18 2.267E-15 4.759E-14 7.870E-20-1.000E+00 1.840E-05 8.490E-12
RED MARR   1.680E-18 5.587E-15 1.173E-13 1.940E-19-1.000E+00 1.520E-04 1.270E-06
BONE SUR   9.300E-18 3.514E-14 7.378E-13 1.220E-18-1.000E+00 1.900E-03 1.580E-05
THYROID    4.010E-18 9.792E-15 2.056E-13 3.400E-19-1.000E+00 9.620E-10 7.990E-12
REMAINDER  1.990E-18 9.216E-15 1.935E-13 3.200E-19-1.000E+00 7.020E-05 6.000E-07
EFFECTIVE  4.880E-18 2.413E-14 5.068E-13 8.380E-19-1.000E+00 1.060E-04 8.650E-07
SKIN(FGR)  4.090E-17 2.776E-13 5.830E-12 9.640E-18-1.000E+00 0.000E+00 0.000E+00
Pu-239
GONADS     4.840E-18 1.768E-14 3.713E-13 6.140E-19-1.000E+00 3.180E-05 2.640E-07
BREAST     7.550E-18 2.238E-14 4.699E-13 7.770E-19-1.000E+00 9.220E-10 7.690E-12
LUNGS      2.650E-18 2.267E-15 4.760E-14 7.870E-20-1.000E+00 1.730E-05 7.740E-12
RED MARR   2.670E-18 3.456E-15 7.258E-14 1.200E-19-1.000E+00 1.690E-04 1.410E-06
BONE SUR   9.470E-18 1.673E-14 3.514E-13 5.810E-19-1.000E+00 2.110E-03 1.760E-05
THYROID    3.880E-18 5.126E-15 1.077E-13 1.780E-19-1.000E+00 9.030E-10 7.490E-12
REMAINDER  2.860E-18 4.838E-15 1.016E-13 1.680E-19-1.000E+00 7.560E-05 6.430E-07
EFFECTIVE  4.240E-18 1.057E-14 2.220E-13 3.670E-19-1.000E+00 1.160E-04 9.560E-07
SKIN(FGR)  1.860E-17 1.057E-13 2.220E-12 3.670E-18-1.000E+00 0.000E+00 0.000E+00
Pu-240
GONADS     6.360E-18 4.118E-14 8.649E-13 1.430E-18-1.000E+00 3.180E-05 2.640E-07
BREAST     1.230E-17 5.328E-14 1.119E-12 1.850E-18-1.000E+00 9.510E-10 7.970E-12
LUNGS      1.090E-18 2.249E-15 4.723E-14 7.810E-20-1.000E+00 1.730E-05 8.070E-12
RED MARR   1.650E-18 5.386E-15 1.131E-13 1.870E-19-1.000E+00 1.690E-04 1.410E-06
BONE SUR   9.260E-18 3.398E-14 7.137E-13 1.180E-18-1.000E+00 2.110E-03 1.760E-05
THYROID    3.920E-18 9.446E-15 1.984E-13 3.280E-19-1.000E+00 9.050E-10 7.510E-12
REMAINDER  1.960E-18 8.870E-15 1.863E-13 3.080E-19-1.000E+00 7.560E-05 6.430E-07
EFFECTIVE  4.750E-18 2.313E-14 4.857E-13 8.030E-19-1.000E+00 1.160E-04 9.560E-07
SKIN(FGR)  3.920E-17 2.644E-13 5.552E-12 9.180E-18-1.000E+00 0.000E+00 0.000E+00
Pu-241
GONADS     7.190E-20 6.653E-17 1.396E-15 2.310E-21-1.000E+00 6.820E-07 5.660E-09
BREAST     8.670E-20 7.229E-17 1.517E-15 2.510E-21-1.000E+00 3.060E-11 2.520E-13
LUNGS      6.480E-20 4.090E-17 8.584E-16 1.420E-21-1.000E+00 7.420E-09 4.450E-13
RED MARR   5.630E-20 4.003E-17 8.403E-16 1.390E-21-1.000E+00 3.360E-06 2.780E-08
BONE SUR   2.190E-19 1.385E-16 2.908E-15 4.810E-21-1.000E+00 4.200E-05 3.480E-07
THYROID    6.980E-20 4.522E-17 9.491E-16 1.570E-21-1.000E+00 1.240E-11 1.010E-13
REMAINDER  6.090E-20 4.291E-17 9.007E-16 1.490E-21-1.000E+00 1.310E-06 1.100E-08
EFFECTIVE  7.250E-20 5.558E-17 1.167E-15 1.930E-21-1.000E+00 2.230E-06 1.850E-08
SKIN(FGR)  1.170E-19 2.033E-16 4.268E-15 7.060E-21-1.000E+00 0.000E+00 0.000E+00
```

7.3 Results

Results for the four cases of the sample-problem involving a unit-curie release of Pu-239 are shown below in Figure 7-2. The results represent the centerline dose as output by MACCS2 with the Type Number 6 output option. The next section contains the output listing for the base case (non-buoyant plume) with the Type Number 6 output highlighted by a box border. The results of Figure 2 demonstrate the role that buoyancy and building wake effects can have on downwind exposures. Additional discussion on this topic is found in Appendix C.

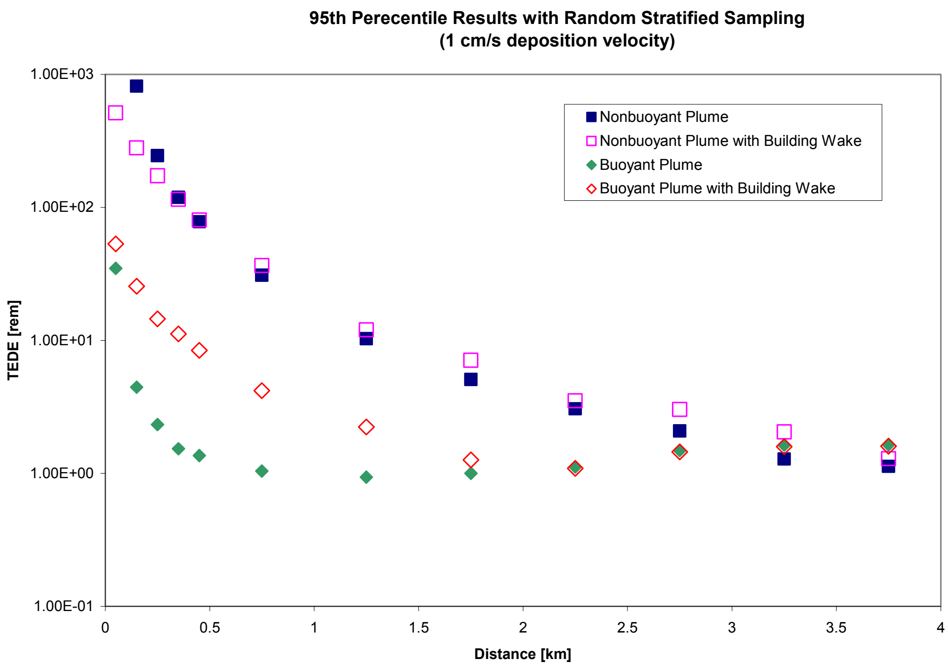

Figure 7-2. MACCS2 results for 4 cases of the sample problem Pu-239 unit curie release

7.4 Output File Listing (with Input Echo)

The output listing for the base case is given below. The output file contains echoes of the ATMOS and EARLY input files. Note that portions of the output listing of been deleted for space considerations. Author's notes in brackets signify where blocks of the output listing are missing. The output of interest for DSA applications is the Type Number 6 output, which signifies centerline doses at a distance. A box border highlights the block of these results below. Following the output listing, changes to the base-case ATMOS files that were necessary to run the other three cases are also documented.

Nonbuoyant Plume (Base Case)

```
MACCS2  9/05/**   17:07:08   Version 1.12, Last Modified 7/01/96 by D. Chanin
 P1:  ATMOS USER INPUT (UNIT 24) = a5_base.INP
 P2:  EARLY USER INPUT (UNIT 25) = e1_tede.INP
 P3: CHRONC USER INPUT (UNIT 26) = ""
 P4:  METEOROLOGY DATA (UNIT 28) = metdata.INP
 P5:   SITE DATA INPUT (UNIT 29) = ""
 P6:       LIST OUTPUT (UNIT 06) = base5_1.OUT



 USER INPUT IS READ FROM UNIT 24
 RECORD IDENTIFIER FIELDS  11 CHARACTERS LONG ARE EXPECTED.
 THE FIRST 100 COLUMNS OF EACH INPUT RECORD ARE PROCESSED.
 THE MAXIMUM NUMBER OF IDENTIFIER RECORDS THAT MAY BE SAVED AS THE BASE CASE IS  1000.

 RECORD
 NUMBER                                   RECORD

        ********************************************************************************
        *
        *         ATMOS FILE
        *INPUT FILE IDENTIFIER
     1  RIATNAM1001  'MACCS2 - Random Stratified Sampling (METCOND=5)'
        ********************************************************************************
        * GEOMETRY DATA BLOCK, LOADED BY INPGEO, STORED IN /GEOM/
        *
        * NUMBER OF RADIAL SPATIAL ELEMENTS
     2  GENUMRAD001 21
        *
        * ENDPOINT DISTANCES TO RADIAL SPATIAL ELEMENTS (KILOMETERS)
     3  GESPAEND001    0.10   0.20   0.30   0.40   0.50   1.00   1.50
     4  GESPAEND002    2.00   2.50   3.00   3.50   4.00   4.50   5.00
     5  GESPAEND003    5.50   6.00   6.50   7.00   7.50   8.00  10.00
        ********************************************************************************
        * ISOTOPE DATA BLOCK, LOADED BY INPISO, STORED IN /ISOGRP/, /ISONAM/
        *
        * NUMBER OF ISOTOPES
     6  ISNUMISO001 1
        *
        * NUMBER OF ISOTOPE GROUPS
     7  ISMAXGRP001 2
        *
        * WET AND DRY DEPOSITION FLAGS FOR EACH ISOTOPE GROUP
        *              WETDEP     DRYDEP
     8  ISDEPFLA001   .FALSE.   .FALSE.
     9  ISDEPFLA002   .FALSE.   .TRUE.
        *
        * NUMBER OF PSEUDOSTABLE NUCLIDES (USED TO TRUNCATE THE DECAY CHAINS)
    10  ISNUMSTB001  6
        *
    11  ISNAMSTB001     U-235     (DAUGHTER OF PU-239)
    12  ISNAMSTB002     Th-231
    13  ISNAMSTB003     Pa-231
    14  ISNAMSTB004     Ac-227
    15  ISNAMSTB005     Fr-223
    16  ISNAMSTB006     Th-227
        *
        * ISOTOPE GROUP DATA FOR ISOTOPE GROUPS
        *               NUCNAM     IGROUP
    17  ISOTPGRP001     Pu-239       2
        *ISOTPGRP002     Pu-238       2
        *
        ********************************************************************************* WET
DEPOSITION DATA
        *
```

```
    * WASHOUT COEFFICIENT NUMBER ONE, LINEAR FACTOR
 18 WDCWASH1001  9.5E-5  (JON HELTON AFTER JONES, 1986)
    *
    * WASHOUT COEFFICIENT NUMBER TWO, EXPONENTIAL FACTOR
 19 WDCWASH2001  0.8  (JON HELTON AFTER JONES, 1986)
    ********************************************************************************
    * DRY DEPOSITION DATA BLOCK, LOADED BY INPDRY, STORED IN /DRYCON/
    *
    * NUMBER OF PARTICLE SIZE GROUPS
 20 DDNPSGRP001  3
    *
    * DEPOSITION VELOCITY OF EACH PARTICLE SIZE GROUP (M/S)
 21 DDVDEPOS001  0.001  0.005  0.01
    ********************************************************************************
    * DISPERSION PARAMETER DATA BLOCK, LOADED BY INPDIS, STORED IN /DISPY/, /DISPZ/
    *
 22 NUM_DIST001   0  (power-law fits used instead of dispersion tables)
    *
    *SIGMA = AX**B WHERE A AND B ARE VALUES FROM TADMOR GUR (1969)
    *
    * STABILITY CLASS: A        B        C        D        E        F
    *
    * LINEAR TERM OF THE EXPRESSION FOR SIGMA-Y, 6 STABILITY CLASSES
 23 DPCYSIGA001   0.3658   0.2751   0.2089   0.1474   0.1046   0.0722
    *
    * EXPONENTIAL TERM OF THE EXPRESSION FOR SIGMA-Y, 6 STABILITY CLASSES
 24 DPCYSIGB001    .9031    .9031    .9031    .9031    .9031    .9031
    *
    * LINEAR TERM OF THE EXPRESSION FOR SIGMA-Z, 6 STABILITY CLASSES
 25 DPCZSIGA001   2.5E-4   1.9E-3       .2       .3       .4       .2
    *
    * EXPONENTIAL TERM OF THE EXPRESSION FOR SIGMA-Z, 6 STABILITY CLASSES
 26 DPCZSIGB001    2.125   1.6021     .8543    .6532    .6021    .6020
    *
    *  LINEAR SCALING FACTOR FOR SIGMA-Y FUNCTION, NORMALLY 1
 27 DPYSCALE001    1.
    *
    *  LINEAR SCALING FACTOR FOR SIGMA-Z FUNCTION,
    *  NORMALLY USED FOR SURFACE ROUGHNESS LENGTH CORRECTION.
    *  (Z1 / Z0) ** .2,   FOR Z1=10 CM, THEREFORE (10/3)**.2=1.27
 28 DPZSCALE001    1.27
    ****************************************************************************** *
    * EXPANSION FACTOR DATA BLOCK, LOADED BY INPEXP, STORED IN /EXPAND/
    *
    * TIME BASE FOR EXPANSION FACTOR (SECONDS)
 29 PMTIMBAS001   180.
    *
    * BREAK POINT FOR FORMULA CHANGE (SECONDS)
 30 PMBRKPNT001   3600.
    *
    * EXPONENTIAL EXPANSION FACTOR NUMBER 1
 31 PMXPFAC1001   .2
    *
    * EXPONENTIAL EXPANSION FACTOR NUMBER 2
 32 PMXPFAC2001   .25
    ********************************************************************************
    * PLUME RISE DATA BLOCK, LOADED BY INPLRS, STORED IN /PLUMRS/
    *
    * SCALING FACTOR FOR THE CRITICAL WIND SPEED FOR ENTRAINMENT OF A BOUYANT PLUME
    * (USED BY FUNCTION CAUGHT)
 33 PRSCLCRW001   1.
    *
    * SCALING FACTOR FOR THE A-D STABILITY PLUME RISE FORMULA
    * (USED BY FUNCTION PLMRIS)
 34 PRSCLADP001   1.
    *
    * SCALING FACTOR FOR THE E-F STABILITY PLUME RISE FORMULA
    * (USED BY FUNCTION PLMRIS)
 35 PRSCLEFP001   1.
```

```
    *****************************************************************************
    * WAKE EFFECTS DATA BLOCK, LOADED BY INPWAK, STORED IN /BILWAK/
    * (minimum value specifcations for open area release)
    * BUILDING WIDTH (METERS) {MACCS 1.5.11.1 Input}
    * WEBUILDW001   1.0
    *
    * BUILDING HEIGHT (METERS) - FOR LIFT OFF CRITERION, BUOYANT PLUME (min. val.)
36  WEBUILDH001   1.0
    *
    * INITIAL VALUE OF SIGMA-Y [METERS] DUE TO WAKE EFFECTS (=Wb/4.3, minimum value)
37  SIGYINIT001    0.1
    *
    * INITIAL VALUE OF SIGMA-Z [METERS] DUE TO WAKE EFFECTS (=Hb/2.15, min. value)
38  SIGZINIT001    0.1
    *
    *****************************************************************************
    * OUTPUT CONTROL DATA BLOCK, LOADED BY INPOPT, STORED IN /STOPME/, /ATMOPT/
    *
    * FLAG TO INDICATE THAT THIS IS THE LAST PROGRAM IN THE SERIES TO BE RUN
39  OCENDAT1001  .FALSE. (SET THIS VALUE TO .TRUE. TO SKIP EARLY AND CHRONC)
40  OCIDEBUG001  0
    *
    * NAME OF THE NUCLIDE TO BE LISTED ON THE DISPERSION LISTINGS
41  OCNUCOUT001  Pu-239
    *****************************************************************************
    * METEOROLOGICAL SAMPLING DATA BLOCK
    *
    * METEOROLOGICAL SAMPLING OPTION CODE:
    * METCOD = 1, USER SPECIFIED DAY AND HOUR IN THE YEAR (FROM MET FILE),
    *          2, WEATHER CATEGORY BIN SAMPLING,
    *          3, 120 HOURS OF WEATHER SPECIFIED ON THE ATMOS USER INPUT FILE,
    *          4, CONSTANT MET (BOUNDARY WEATHER USED FROM THE START),
    *          5, STRATIFIED RANDOM SAMPLES FOR EACH DAY OF THE YEAR.
42  M1METCOD001  5
    *
    * LAST SPATIAL INTERVAL FOR MEASURED WEATHER
43  M2LIMSPA001  21
    *
    * BOUNDARY WEATHER MIXING LAYER HEIGHT
44  M2BNDMXH001   600.  (METERS)
    *
    * BOUNDARY WEATHER STABILITY CLASS INDEX
45  M2IBDSTB001  6      (F-STABILITY)
    *
    * BOUNDARY WEATHER RAIN RATE
46  M2BNDRAN001  5.     (MM/HR)
    *
    * BOUNDARY WEATHER WIND SPEED
47  M2BNDWND001  1.    (M/S)
    *
    ****************************************************************************
    * START DAY
    * M3ISTRDY001  237
    * START HOUR
    * M3ISTRHR001  1
    *
    * NUMBER OF RAIN DISTANCE INTERVALS FOR BINNING
    * M4NRNINT001  6
    *
    * ENDPOINTS OF THE RAIN DISTANCE INTERVALS (KILOMETERS)
    * NOTE: THESE MUST BE CHOSEN TO MATCH THE SPATIAL ENDPOINT DISTANCES
    *       SPECIFIED FOR THE ARRAY SPAEND (10 % ERROR IS ALLOWED).
    * M4RNDSTS001  0.2  0.5  1.0  1.5  2.0  3.5
    *
    * NUMBER OF RAIN INTENSITIY BREAKPOINTS
    *M4NRINTN001   2
    *
    * RAIN INTENSITY BREAKPOINTS FOR WEATHER BINNING (MILLIMETERS PER HOUR)
    * M4RNRATE001   1.  2.
```

```
    ******************************************************************************
    * NUMBER OF SAMPLES PER BIN
    *
48  M4NSMPLS001  24
    *
    * INITIAL SEED FOR RANDOM NUMBER GENERATOR
49  M4IRSEED001  93
    ******************************************************************************
    * RELEASE DATA BLOCK, LOADED BY INPREL, STORED IN /ATNAM2/, /MULREL/
    *
    * SOURCE TERM RELEASE SPECIFIC INFORMATION
50  RDATNAM2001 'Unit Ci release Pu-239 w/ nonbuoyant (open area) - YR'
    *
    * TIME AFTER ACCIDENT INITIATION WHEN THE ACCIDENT REACHES GENERAL EMERGENCY
    * CONDITIONS (AS DEFINED IN NUREG-0654), OR WHEN PLANT PERSONNEL CAN RELIABLY
    * PREDICT THAT GENERAL EMERGENCY CONDITIONS WILL BE ATTAINED
    *
51  RDOALARM001    0.00E+00
    *
    * NUMBER OF PLUME SEGMENTS THAT ARE RELEASED
52  RDNUMREL001     1
    *
    * SELECTION OF RISK DOMINANT PLUME
53  RDMAXRIS001     1
    *
    * REFERENCE TIME FOR DISPERSION AND RADIOACTIVE DECAY
54  RDREFTIM001       0.00
    * CORRESPONDING TO LEADING EDGE WEATHER
    *
    * HEAT CONTENT OF THE RELEASE SEGMENTS (WATTS)
    * A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
55  RDPLHEAT001   0.0
    *
    * HEIGHT OF THE PLUME SEGMENTS AT RELEASE (METERS)
    * A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
56  RDPLHITE001  0.0
    *
    * DURATION OF THE PLUME SEGMENTS (SECONDS)
    * A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
57  RDPLUDUR001   600.0
    *
    * TIME OF RELEASE FOR EACH PLUME (SECS FROM SCRAM)
    * A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
58  RDPDELAY001   0.0
    *
    * PARTICLE SIZE DISTRIBUTION OF EACH ISOTOPE GROUP
    * YOU MUST SPECIFY A COLUMN OF DATA FOR EACH OF THE PARTICLE SIZE GROUPS
    *
    *  V dep = 0.001 is for a filtered release
    *  V dep = 0.005 is for HTO only
    *  V dep = 0.010 is for an unfiltered release
    *
    *              0.001  0.005  0.010
59  RDPSDIST001    1.000  0.000  0.000
60  RDPSDIST002    0.000  0.000  1.000
    *
    *                NUCNAM      CORINV(Unit Ci Release)
61  RDCORINV001      Pu-239         1.00E+00
    *RDCORINV002      Pu-238         0.00E+00
    *
    *  SCALING FACTOR TO ADJUST THE CORE INVENTORY
62  RDCORSCA001  3.7E+10 (Conversion of Curies to Becquerels)
    *
    * RELEASE FRACTIONS FOR ISOTOPE GROUPS IN RELEASE
    * GROUP     XE/KR    I    CS    TE    SR    RU    LA    CE    BA   TRIT
63  RDRELFRC001   1.0  1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0
    *
    * RELEASE FREACTION APPLICATION TO INGROWTH DECAY PRODUCTS
    * PRODUCED AFTER ACCIDENT INITIATION
```

```
   64  RDAPLFRC001    PARENT
       *
       * REQUEST FOR ATMOSPHERIC OUTPUT INFORMATION
       *
       *            NUM0
   65  TYPE0NUMBER    4
       *
       *            INDREL     INRAD
   66  TYPE0OUT001      1         1
   67  TYPE0OUT002      1         2
   68  TYPE0OUT003      1        10
   69  TYPE0OUT004      1        21    CCDF
       *
       ********************
       .
 ******** TERMINATOR RECORD ENCOUNTERED -- END OF BASE CASE USER INPUT ********


 USER INPUT PROCESSING SUMMARY - BASE CASE

 NUMBER OF RECORDS READ                          =  268
 NUMBER OF BLANK OR COMMENT RECORDS READ         =  198
 NUMBER OF TERMINATOR RECORDS                    =    1
 NUMBER OF RECORDS PROCESSED                     =   69
      NUMBER OF PROCESSED RECORDS DUPLICATED     =    0
      NUMBER OF PROCESSED RECORDS SORTED         =   69

************************************************************************************************
***



 Decay Chain #  Pu-239


 RELEASED INVENTORY OF ALL PLUMES
 Pu-239     3.70E+10

 READING FROM A WEATHER FILE WITH THE FOLLOWING HEADER:
 SAMPLE MET DATA FILE
 3/05/01  PROCESSED MET DATA FOR MACCS2 USE
      METEOROLOGICAL DATA FILE CONTAINS  255 HOURS OF OBSERVED RAIN DATA.
             ACCUMULATED RAIN MEASUREMENTS TOTALED   9.63 INCHES FOR THE YEAR.
             CONSTANT LID HEIGHTS (M) FOR 4 SEASONS =     600    600    600    600
             NON-ZERO WINDSPEEDS LESS THAN 0.5 M/S ARE SET TO 0.5 M/S


 USER INPUT IS READ FROM UNIT 25
 RECORD IDENTIFIER FIELDS  11 CHARACTERS LONG ARE EXPECTED.
 THE FIRST 100 COLUMNS OF EACH INPUT RECORD ARE PROCESSED.
 THE MAXIMUM NUMBER OF IDENTIFIER RECORDS THAT MAY BE SAVED AS THE BASE CASE IS  1000.

 RECORD
 NUMBER                                  RECORD

       ********************************************************************************
       * GENERAL DESCRIPTIVE TITLE DESCRIBING THIS "EARLY" INPUT FILE
       *
     1  MIEANAM1001  'MACCS - TEDE'
       *
       * DCF FILE IDENTIFICATION
     2  DCF_FILE001     'FGR_PU.INP'
       *
       * FLAG TO INDICATE THAT THIS IS THE LAST PROGRAM IN THE SERIES TO BE RUN
       *
     3  MIENDAT2001  .TRUE.    (SET THIS VALUE TO .TRUE. TO SKIP CHRONC)
       *
       * DISPERSION MODEL OPTION CODE:  1  *  STRAIGHT LINE
       *                                2  *  WIND-SHIFT WITH ROTATION
```

```
     *                                3  *  WIND-SHIFT WITHOUT ROTATION
     *
  4  MIIPLUME001  1
     *
     * NUMBER OF FINE GRID SUBDIVISIONS USED BY THE MODEL
     *
  5  MINUMFIN001  7    (3, 5 OR 7 ALLOWED)
     *
     * LEVEL OF DEBUG OUTPUT REQUIRED, NORMAL RUNS SHOULD SPECIFY ZERO
     *
  6  MIIPRINT001  0
     *
     * LOGICAL FLAG SIGNIFYING THAT THE BREAKDOWN OF RISK BY WEATHER CATEGORY
     * BIN ARE TO BE PRESENTED TO SHOW THEIR RELATIVE CONTRIBUTION TO THE MEAN
     *
     *             RISBIN
     *
  7  MIRISCAT001   .FALSE.
     *
     * FLAG INDICATING IF WIND-ROSES FROM ATMOS ARE TO BE OVERRIDDEN
     *
  8  MIOVRRID001  .FALSE.  (USE THE WIND ROSE CALCULATED FOR EACH WEATHER BIN)
     ********************************************************************************
     * POPULATION DISTRIBUTION DATA BLOCK, LOADED BY INPOPU, STORED IN /POPDAT/
     *
     *PDPOPFLG001  FILE
     *
  9  PDPOPFLG001  UNIFORM
 10  PDIBEGIN001  1   (SPATIAL INTERVAL AT WHICH POPULATION BEGINS)
 11  PDPOPDEN001  0. (POPULATION DENSITY (PEOPLE PER SQUARE KILOMETER))
     ********************************************************************************
     * ORGAN DEFINITION DATA BLOCK, LOADED BY INORGA, STORED IN /EARDIM/ AND /ORGNAM/
     *
     *                ORGAN NAME             ORGFLG
     *
     *MIORGDEF001      'A-SKIN'                .FALSE.
     *MIORGDEF002      'A-RED MARR'            .FALSE.
     *MIORGDEF003      'A-LUNGS'               .FALSE.
     *MIORGDEF004      'A-THYROIDH'            .FALSE.
     *MIORGDEF005      'A-STOMACH'             .FALSE.
     *MIORGDEF006      'A-LOWER LI'            .FALSE.
     *MIORGDEF007      'L-EFFECTIVE'            .TRUE.
     *MIORGDEF008      'L-RED MARR'            .FALSE.
     *MIORGDEF009      'L-BONE SUR'            .FALSE.
     *MIORGDEF010      'L-BREAST'              .FALSE.
     *MIORGDEF011      'L-LUNGS'               .FALSE.
     *MIORGDEF012      'L-THYROID'             .FALSE.
     *MIORGDEF013      'L-LOWER LI'            .FALSE.
     *MIORGDEF014      'L-BLAD WAL'            .FALSE.
     *MIORGDEF015      'L-LIVER'               .FALSE.
     *MIORGDEF016      'L-THYROIDH'            .FALSE.
     *
     ********************************************************************************
     * SHIELDING AND EXPOSURE FACTORS, LOADED BY INDFAC, STORED IN /EADFAC/
     *
     * THREE VALUES OF EACH PROTECTION FACTOR ARE SUPPLIED,
     * ONE FOR EACH TYPE OF ACTIVTY:
     *
     * ACTIVITY TYPE:
     *     1 - EVACUEES WHILE MOVING
     *     2 - NORMAL ACTIVITY IN SHELTERING AND EVACUATION ZONE
     *     3 - SHELTERED ACTIVITY
     *
     * CLOUD SHIELDING FACTOR
     *
     *            EVACUEES  NORMAL  SHELTER
     *
 12  SECSFACT001      1.     1.     1.
     *
```

```
     * PROTECTION FACTOR FOR INHALATION
     *
13   SEPROTIN001      1.     1.     1.
     *
     * BREATHING RATE (CUBIC METERS PER SECOND)
     *
14   SEBRRATE001  3.33E-4  3.33E-4  3.33E-4
     *
     * SKIN PROTECTION FACTOR
     *
15   SESKPFAC001      1.     1.     1.
     *
     * GROUND SHIELDING FACTOR
     *
16   SEGSHFAC001      1.    1.     1.
     *
     * RESUSPENSION INHALATION MODEL CONCENTRATION COEFFICIENT (/METER)
     *
     *   RESCON = 1.E-4 IS APPROPRIATE FOR MECHANICAL RESUSPENSION BY VEHICLES.
     *   RESHAF = 2.11 DAYS CAUSES 1.E-4 TO DECAY IN ONE WEEK TO 1.E-5, THE VALUE
     *   OF RESCON USED IN THE FIRST TERM OF THE LONG-TERM RESUSPENSION EQUATION
     *   USED IN CHRONC.
     *
17   SERESCON001   1.0E-4     (RESUSPENSION IS TURNED ON)
     *
     * RESUSPENSION CONCENTRATION COEFFICIENT HALF-LIFE (SEC)
     *
18   SERESHAF001   1.825E5  (2.11 DAYS)
     *******************************************************************************
     * EVACUATION ZONE DATA BLOCK, LOADED BY EVNETW, STORED IN /NETWOR/, /EOPTIO/
     *
     * SPECIFIC DESCRIPTION OF THE EMERGENCY RESPONSE SCENARIO BEING USED
     *
19   EZEANAM2001  'NO EVACUATION OR SHELTERING'
     *
     * THE TYPE OF WEIGHTING TO BE APPLIED TO THE EMERGENCY RESPONSE SCENARIOS
     * YOU MUST SUPPLY A VALUE OF 'TIME' OR 'PEOPLE'
     *
                20  EZWTNAME001  'PEOPLE'
     *
     *
     * WEIGHTING FRACTION APPLICABLE TO THIS SCENARIO
     *
21   EZWTFRAC001  1.000
     *
     * LAST RING IN THE MOVEMENT ZONE
     *
22   EZLASMOV001     0    (NO EVACUATION)
     *
     * FIRST SPATIAL INTERVAL IN THE EVACUATION ZONE
     *
     **********************************************************************
     * SHELTER AND RELOCATION ZONE DATA BLOCK, LOADED BY INPEMR,
     *                                          STORED IN /INPSRZ/, /RELOCA/
     *
     * TIME TO TAKE SHELTER IN THE INNER SHELTER ZONE (SECONDS FROM OALARM)
     *
     *SRTTOSH1001      0.    (THERE IS NO INNER SHELTER ZONE)
     *
     * SHELTER DURATION IN THE INNER SHELTER ZONE (SECONDS FROM TAKING SHELTER)
     *
     *SRSHELT1001      0.    (THERE IS NO INNER SHELTER ZONE)
     *
     * LAST RING OF THE OUTER SHELTER ZONE
     *
     *SRLASHE2001      0     (THERE IS NO OUTER SHELTER ZONE)
     *
     * TIME TO TAKE SHELTER IN THE OUTER SHELTER ZONE (SECONDS FROM OALARM)
     *
```

```
    *SRTTOSH2001      0.    (THERE IS NO OUTER SHELTER ZONE)
    *
    * SHELTER DURATION IN THE OUTER SHELTER ZONE (SECONDS FROM TAKING SHELTER)
    *
    *SRSHELT2001      0.    (THERE IS NO OUTER SHELTER ZONE)
    *
    * DURATION OF THE EMERGENCY PHASE (SECONDS FROM PLUME ARRIVAL)
    *
23  SRENDEMP001  86400.   (ONE DAY)
    *
    * CRITICAL ORGAN FOR RELOCATION DECISIONS
    *
24  SRCRIORG001 'L-EFFECTIVE'
    *
    * HOT SPOT RELOCATION TIME (SECONDS FROM PLUME ARRIVAL)
    *
25  SRTIMHOT001  86400.   (ONE DAY)
    *
    * NORMAL RELOCATION TIME (SECONDS FROM PLUME ARRIVAL)
    *
26  SRTIMNRM001  86400.   (ONE DAY)
    *
    * HOT SPOT RELOCATION DOSE CRITERION THRESHOLD (SIEVERTS)
    *
27  SRDOSHOT001  0.50  (50 REM DOSE TO RBM IN 1 WEEK TRIGGERS RELOCATION)
    *
    * NORMAL RELOCATION DOSE CRITERION THRESHOLD (SIEVERTS)
    *
28  SRDOSNRM001  0.25   (25 REM DOSE TO RBM IN 1 WEEK TRIGGERS RELOCATION)
    ********************************************************************************
    * EARLY FATALITY MODEL PARAMETERS, LOADED BY INEFAT, STORED IN /EFATAL/
    *
    * NUMBER OF EARLY FATALITY EFFECTS
    *
29  EFNUMEFA001   0
    *
    ********************************************************************************
    * EARLY INJURY MODEL PARAMETERS, LOADED BY INEINJ, STORED IN /EINJUR/
    *
    * NUMBER OF EARLY INJURY EFFECTS
    *
30  EINUMEIN001  0
    *
    ********************************************************************************
    * ACUTE EXPOSURE CANCER PARAMETERS, LOADED BY INACAN STORED IN /ACANCR/.
    *
    * NUMBER OF ACUTE EXPOSURE CANCER EFFECTS**
    *
31  LCNUMACA001   0
    *
    * THRESHOLD DOSE FOR APPLYING THE DOSE DEPENDENT REDUCTION FACTOR
    *
    * LCDDTHRE001   0.0  (LOWEST DOSE FOR WHICH DDREFA WILL BE APPLIED)
    *
    * DOSE THRESHOLD FOR LINEAR DOSE RESPONSE (Sv)
    *
    * LCACTHRE001   1.5  (LINEAR-QUADRATIC MODEL IS NOT BEING USED)
    *
    *            ACNAME       ORGNAM  ACSUSC  DOSEFA DOSEFB  CFRISK  CIRISK  DDREFA
    *
    * LCANCERS001 'ICRP 60' 'L-EFFECTIVE' 1.0   1.0    0.0    5.0E-2  7.3E-2   1.0
    ********************************************************************************
    * RESULT 1 OPTIONS BLOCK, LOADED BY INOUT1, STORED IN /INOUT1/
    * TOTAL NUMBER OF A GIVEN EFFECT (LATENT CANCER, EARLY DEATH, EARLY INJURY)
    * NUMBER OF DESIRED RESULTS OF THIS TYPE
32  TYPE1NUMBER    0
    *******************************************************************************
    * RESULT 2 OPTIONS BLOCK, LOADED BY INOUT2, STORED IN /INOUT2/
    * FURTHEST DISTANCE AT WHICH A GIVEN RISK OF EARLY DEATH IS EXCEEDED.
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    * NUMBER OF DESIRED RESULTS OF THIS TYPE
    *
33  TYPE2NUMBER  0
    ******************************************************************************
    * RESULT 3 OPTIONS BLOCK, LOADED BY INOUT3, STORED IN /INOUT3/
    * NUMBER OF PEOPLE WHOSE DOSE TO A GIVEN ORGAN EXCEEDS A GIVEN THRESHOLD.
    * NUMBER OF DESIRED RESULTS OF THIS TYPE
34  TYPE3NUMBER  0
    ******************************************************************************
    * RESULT 4 OPTIONS BLOCK, LOADED BY INOUT4, STORED IN /INOUT4/
    * 360 DEGREE AVERAGE RISK OF A GIVEN EFFECT AT A GIVEN DISTANCE.
    * POSSIBLE TYPES OF EFFECTS ARE:
35  TYPE4NUMBER  0
    ******************************************************************************
    * RESULT 5 OPTIONS BLOCK, LOADED BY INOUT5, STORED IN /INOUT5/
    * TOTAL POPULATION DOSE TO A GIVEN ORGAN BETWEEN TWO DISTANCES.
    * NUMBER OF DESIRED RESULTS OF THIS TYPE
36  TYPE5NUMBER     0
    ******************************************************************************
    * RESULT 6 OPTIONS BLOCK, LOADED BY INOUT6, STORED IN /INOUT6/
    * CENTERLINE DOSE TO AN ORGAN VS DIST BY PATHWAY, PATHWAY NAMES ARE AS FOLLOWS:
    *  PATHWAY NAME:
    *    'CLD'     - CLOUDSHINE
    *    'GRD'     - GROUNDSHINE
    *    'INH ACU' - "ACUTE DOSE EQUIVALENT" FROM DIRECT INHALATION OF THE CLOUD
    *    'INH LIF' - "LIFETIME DOSE COMMITMENT" FROM DIRECT INHALATION OF THE CLOUD
    *    'RES ACU' - "ACUTE DOSE EQUIVALENT" FROM RESUSPENSION INHALATION
    *    'RES LIF' - "LIFETIME DOSE COMMITMENT" FROM RESUSPENSION INHALATION
    *    'TOT ACU' - "ACUTE DOSE EQUIVALENT" FROM ALL PATHWAYS
    *    'TOT LIF' - "LIFETIME DOSE COMMITMENT" FROM ALL PATHWAYS
    * NUMBER OF DESIRED RESULTS OF THIS TYPE
37  TYPE6NUMBER     1
    *
    *             ORGNAM        PATHNM      I1DIS6   I2DIS6
    *
38  TYPE6OUT001  'L-EFFECTIVE'    'TOT LIF'      1       21
    *TYPE6OUT002  'L-EFFECTIVE'    'TOT LIF'      2       2
    *TYPE6OUT003  'L-EFFECTIVE'    'TOT LIF'      3       3
    *TYPE6OUT004  'L-EFFECTIVE'    'TOT LIF'      4       4
    ******************************************************************************
    * RESULT 7 OPTIONS BLOCK, LOADED BY INOUT7, STORED IN /INOUT7/
    * CENTERLINE RISK OF A GIVEN EFFECT VS DISTANCE
    * NUMBER OF DESIRED RESULTS OF THIS TYPE
39  TYPE7NUMBER   0
    ******************************************************************************
    * RESULT 8 OPTIONS BLOCK, LOADED BY INOUT8, STORED IN /INOUT8/
    * POPULATION WEIGHTED FATALITY RISK BETWEEN 2 DISTANCES
    * NUMBER OF DESIRED RESULTS OF THIS TYPE
40  TYPE8NUMBER   0
    ******************************************************************************
    * RESULT A OPTIONS BLOCK, LOADED BY INOUTA, STORED IN /INOUTA/
    * PEAK TOTAL DOSE AT A DISTANCE
    * NUMBER OF DESIRED RESULTS OF THIS TYPE
41  TYPEANUMBER   1
    *             ORGNAM            I1DISA   I2DISA
    *
42  TYPEAOUT001  'L-EFFECTIVE'          1       21
    ******************************************************************************
    * RESULT B OPTIONS BLOCK, LOADED BY INOUTB, STORED IN /INOUTB/
    * PEAK TOTAL DIRECT DOSE FOUND AT A SPATIAL GRID LOCATION
    * NUMBER OF DESIRED RESULTS OF THIS TYPE
43  TYPEBNUMBER   16
    *             ORGNAM            I1DISB   I2DISB
    *
44  TYPEBOUT001  'L-EFFECTIVE'          3       1
45  TYPEBOUT002  'L-EFFECTIVE'          3       2
46  TYPEBOUT003  'L-EFFECTIVE'          3       3
47  TYPEBOUT004  'L-EFFECTIVE'          3       4
48  TYPEBOUT005  'L-EFFECTIVE'          3       5
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   49  TYPEBOUT006  'L-EFFECTIVE'          3       6
   50  TYPEBOUT007  'L-EFFECTIVE'          3       7
   51  TYPEBOUT008  'L-EFFECTIVE'          3       8
   52  TYPEBOUT009  'L-EFFECTIVE'          3       9
   53  TYPEBOUT010  'L-EFFECTIVE'          3      10
   54  TYPEBOUT011  'L-EFFECTIVE'          3      11
   55  TYPEBOUT012  'L-EFFECTIVE'          3      12
   56  TYPEBOUT013  'L-EFFECTIVE'          3      13
   57  TYPEBOUT014  'L-EFFECTIVE'          3      14
   58  TYPEBOUT015  'L-EFFECTIVE'          3      15
   59  TYPEBOUT016  'L-EFFECTIVE'          3      16
       ********************************************************************************
       .
 ******** TERMINATOR RECORD ENCOUNTERED -- END OF BASE CASE USER INPUT ********


 USER INPUT PROCESSING SUMMARY - BASE CASE

 NUMBER OF RECORDS READ                           =  303
 NUMBER OF BLANK OR COMMENT RECORDS READ          =  243
 NUMBER OF TERMINATOR RECORDS                     =    1
 NUMBER OF RECORDS PROCESSED                      =   59
      NUMBER OF PROCESSED RECORDS DUPLICATED      =    0
      NUMBER OF PROCESSED RECORDS SORTED          =   59

*************************************************************************************************
***



 The list of defined organs from FGRDCF is as follows (A- is ACUTE and L- is LIFETIME):
    A-SKIN
    A-SKIN(FGR)
    L-GONADS
    L-BREAST
    L-LUNGS
    L-RED MARR
    L-BONE SUR
    L-THYROID
    L-REMAINDER
    L-EFFECTIVE

 READING FROM A DOSE CONVERSION FILE WITH THE FOLLOWING HEADER:
 FGRDCF 06/18/02   12:22:20   BETA-TEST VERSION 1.10, MINOR FORTRAN FIXES 5/4/95
 IMPLICIT DAUGHTER HALFLIVES (M) LESS THAN  90 AND LESS THAN 0.100 OF PARENT

 Processing DCFs for Pu-239
 NO EVACUATION REQUESTED

 CALCULATING A UNIFORM POPULATION DISTRIBUTION

1 THIS PROGRAM CURRENTLY ALLOWS THE GENERATION OF UP TO  394 RESULTS

 YOU HAVE REQUESTED  58 RESULTS FROM "EARLY" COMPOSED OF:

    0 RESULTS OF TYPE 1
    0 RESULTS OF TYPE 2
    0 RESULTS OF TYPE 3
    0 RESULTS OF TYPE 4
    0 RESULTS OF TYPE 5
   21 RESULTS OF TYPE 6
    0 RESULTS OF TYPE 7
    0 RESULTS OF TYPE 8
   21 RESULTS OF TYPE A
   16 RESULTS OF TYPE B


      TRIAL        DAY       HOUR        BIN     PRBMET
          1          1          1          0   1.14E-04
```

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 Each weather sequence has a probability of 1.142E-04

          2          1          2          0   1.14E-04
          3          1          3          0   1.14E-04
          4          1          4          0   1.14E-04
          5          1          5          0   1.14E-04
          6          1          6          0   1.14E-04
          7          1          7          0   1.14E-04
          8          1          8          0   1.14E-04
          9          1          9          0   1.14E-04

[Authors' Note:  Only small sample of 8760 trials are documented here]


      TRIAL        DAY       HOUR        BIN      PRBMET
        8751        365         15          0   1.14E-04
        8752        365         16          0   1.14E-04
        8753        365         17          0   1.14E-04
        8754        365         18          0   1.14E-04
        8755        365         19          0   1.14E-04
        8756        365         20          0   1.14E-04
        8757        365         21          0   1.14E-04
        8758        365         22          0   1.14E-04
        8759        365         23          0   1.14E-04
        8760        365         24          0   1.14E-04
1  DATE AND TIME OF RUN = MACCS2  9/05/**   17:07:08   Version 1.12, Last Modified 7/01/96 by D.
Chanin
   "ATMOS"  DESCRIPTION = MACCS2 - Random Stratified Sampling (METCOND=5)
                                          PROB                           QUANTILES
PEAK      PEAK  PEAK
                                        NON-ZERO   MEAN      50TH      90TH      95TH      99TH
99.5TH     CONS      PROB  TRIAL
 Source Term 1: Plume 1, at     0- .1 km
  Pu-239   Center Air Conc. (Bq-s/m3)     .9999  5.92E+08  1.97E+08  2.23E+09 NOT-FOUND NOT-FOUND
NOT-FOUND  2.74E+09  8.08E-02   23
  Pu-239   Ground Air Conc. (Bq-s/m3)     .9999  5.92E+08  1.97E+08  2.23E+09 NOT-FOUND NOT-FOUND
NOT-FOUND  2.74E+09  8.08E-02   23
  Pu-239   Center Ground Conc. (Bq/m2)    .9999  5.77E+06  1.97E+06  2.20E+07 NOT-FOUND NOT-FOUND
NOT-FOUND  2.62E+07  8.08E-02   23
  Total    Center Ground Conc. (Bq/m2)    .9999  5.77E+06  1.97E+06  2.20E+07 NOT-FOUND NOT-FOUND
NOT-FOUND  2.62E+07  8.08E-02   23
  Ground-Level Dilution, X/Q (s/m3)       .9999  1.97E-02  5.60E-03  7.93E-02 NOT-FOUND NOT-FOUND
NOT-FOUND  1.01E-01  8.08E-02   23
  Pu-239   Adjusted Source, Q (Bq)        .9999  3.41E+10  3.04E+10  3.15E+10  3.20E+10  3.32E+10
3.37E+10  3.67E+10  1.14E-04  941
  Plume Sigma-y (m)                       .9999  6.13E+00  5.39E+00  9.80E+00  1.26E+01 NOT-FOUND
NOT-FOUND  1.50E+01  3.11E-02  135
  Plume Sigma-z (m)                       .9999  3.85E+00  3.38E+00 NOT-FOUND NOT-FOUND NOT-FOUND
NOT-FOUND  6.56E+00  1.21E-01   11
  Plume Height  (m)                       .0000  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00    0
  Plume Arrival Time (s)                  .9999  3.60E+01  2.31E+01 NOT-FOUND NOT-FOUND NOT-FOUND
NOT-FOUND  1.00E+02  1.22E-01   23

 Source Term 1: Plume 1, at    .1- .2 km
  Pu-239   Center Air Conc. (Bq-s/m3)     .9999  5.87E+07  2.40E+07  2.06E+08 NOT-FOUND NOT-FOUND
NOT-FOUND  2.18E+08  8.08E-02   23
  Pu-239   Ground Air Conc. (Bq-s/m3)     .9999  5.87E+07  2.40E+07  2.06E+08 NOT-FOUND NOT-FOUND
NOT-FOUND  2.18E+08  8.08E-02   23
  Pu-239   Center Ground Conc. (Bq/m2)    .9999  5.85E+05  2.40E+05  2.06E+06 NOT-FOUND NOT-FOUND
NOT-FOUND  2.16E+06  8.08E-02   23
  Total    Center Ground Conc. (Bq/m2)    .9999  5.85E+05  2.40E+05  2.06E+06 NOT-FOUND NOT-FOUND
NOT-FOUND  2.16E+06  8.08E-02   23
  Ground-Level Dilution, X/Q (s/m3)       .9999  2.80E-03  7.26E-04  1.14E-02 NOT-FOUND NOT-FOUND
NOT-FOUND  1.46E-02  8.08E-02   23
  Pu-239   Adjusted Source, Q (Bq)        .9999  3.03E+10  3.02E+10  3.13E+10  3.18E+10  3.29E+10
3.34E+10  3.63E+10  1.14E-04  941
  Plume Sigma-y (m)                       .9999  1.74E+01  1.30E+01  2.93E+01  3.68E+01 NOT-FOUND
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```
NOT-FOUND  4.28E+01  3.11E-02  135
  Plume Sigma-z (m)                       .9999  1.04E+01  8.61E+00 NOT-FOUND NOT-FOUND NOT-FOUND
NOT-FOUND  1.83E+01  1.21E-01   11
  Plume Height  (m)                       .0000  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00    0
  Plume Arrival Time (s)                  .9999  1.08E+02  6.88E+01 NOT-FOUND NOT-FOUND NOT-FOUND
NOT-FOUND  3.00E+02  1.22E-01   23

 Source Term 1: Plume 1, at   2.5-3.0 km
  Pu-239   Center Air Conc. (Bq-s/m3)     .9999  2.21E+05  1.77E+05  4.54E+05  5.42E+05  7.01E+05
7.06E+05  7.16E+05  1.37E-03   55
  Pu-239   Ground Air Conc. (Bq-s/m3)     .9999  2.21E+05  1.77E+05  4.54E+05  5.42E+05  7.01E+05
7.06E+05  7.16E+05  1.37E-03   55
  Pu-239   Center Ground Conc. (Bq/m2)    .9999  2.21E+03  1.77E+03  4.52E+03  5.41E+03  7.01E+03
7.06E+03  7.16E+03  1.37E-03   55
  Total    Center Ground Conc. (Bq/m2)    .9999  2.21E+03  1.77E+03  4.52E+03  5.41E+03  7.01E+03
7.06E+03  7.16E+03  1.37E-03   55
  Ground-Level Dilution, X/Q (s/m3)       .9999  3.04E-05  7.45E-06  1.10E-04  1.69E-04 NOT-FOUND
NOT-FOUND  1.82E-04  4.42E-02   66
  Pu-239   Adjusted Source, Q (Bq)        .9999  2.22E+10  2.33E+10  3.06E+10  3.10E+10  3.19E+10
3.24E+10  3.47E+10  1.14E-04 6466
  Plume Sigma-y (m)                       .9999  2.42E+02  2.19E+02  3.70E+02  4.46E+02 NOT-FOUND
NOT-FOUND  5.94E+02  3.22E-02  135
  Plume Sigma-z (m)                       .9999  1.29E+02  5.70E+01  2.58E+02  7.09E+02  7.76E+02
8.07E+02  1.15E+03  1.14E-04 6970
  Plume Height  (m)                       .0000  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00    0
  Plume Arrival Time (s)                  .9999  1.95E+03  1.23E+03  4.91E+03 NOT-FOUND NOT-FOUND
NOT-FOUND  5.50E+03  8.50E-02   66

 Source Term 1: Plume 1, at  8.0-10.0 km
  Pu-239   Center Air Conc. (Bq-s/m3)     .9999  2.19E+04  1.67E+04  4.47E+04  5.89E+04  9.34E+04
1.06E+05  1.84E+05  1.14E-04 7681
  Pu-239   Ground Air Conc. (Bq-s/m3)     .9999  2.19E+04  1.67E+04  4.47E+04  5.89E+04  9.34E+04
1.06E+05  1.84E+05  1.14E-04 7681
  Pu-239   Center Ground Conc. (Bq/m2)    .9999  2.19E+02  1.66E+02  4.46E+02  5.87E+02  9.30E+02
1.06E+03  1.83E+03  1.14E-04 7681
  Total    Center Ground Conc. (Bq/m2)    .9999  2.19E+02  1.66E+02  4.46E+02  5.87E+02  9.30E+02
1.06E+03  1.83E+03  1.14E-04 7681
  Ground-Level Dilution, X/Q (s/m3)       .9999  4.01E-06  1.01E-06  1.27E-05  2.00E-05 NOT-FOUND
NOT-FOUND  3.06E-05  1.11E-02   66
  Pu-239   Adjusted Source, Q (Bq)        .9999  1.88E+10  2.07E+10  3.01E+10  3.05E+10  3.14E+10
3.17E+10  3.39E+10  1.14E-04 6466
  Plume Sigma-y (m)                       .9999  7.21E+02  5.64E+02  1.04E+03  1.17E+03  1.56E+03
NOT-FOUND  1.73E+03  5.59E-03  709
  Plume Sigma-z (m)                       .9999  2.00E+02  1.37E+02  5.04E+02  5.56E+02  6.96E+02
8.14E+02  1.15E+03  1.14E-04 1402
  Plume Height  (m)                       .0000  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00    0
  Plume Arrival Time (s)                  .9999  6.08E+03  4.06E+03  1.30E+04  1.68E+04 NOT-FOUND
NOT-FOUND  1.80E+04  4.18E-02   66
1 RESULT NAME = Source Term 1: Plume 1, at  8.0-10.0 km
                   Pu-239   Center Air Conc. (Bq-s/m3)
  1.00E-02  1.00E+00
  2.00E-02  1.00E+00
  3.00E-02  1.00E+00
  5.00E-02  1.00E+00
  7.00E-02  1.00E+00
  1.00E-01  1.00E+00
  2.00E-01  1.00E+00
  3.00E-01  1.00E+00
  5.00E-01  1.00E+00
  7.00E-01  1.00E+00
  1.00E+00  1.00E+00
  2.00E+00  1.00E+00
  3.00E+00  1.00E+00
  5.00E+00  1.00E+00
  7.00E+00  1.00E+00
  1.00E+01  1.00E+00
```

```
  2.00E+01  1.00E+00
  3.00E+01  1.00E+00
  5.00E+01  1.00E+00
  7.00E+01  1.00E+00
  1.00E+02  1.00E+00
  2.00E+02  1.00E+00
  3.00E+02  1.00E+00
  5.00E+02  9.98E-01
  7.00E+02  9.95E-01
  1.00E+03  9.90E-01
  2.00E+03  9.79E-01
  3.00E+03  9.57E-01
  5.00E+03  8.57E-01
  7.00E+03  7.24E-01
  1.00E+04  6.54E-01
  2.00E+04  4.54E-01
  3.00E+04  2.33E-01
  5.00E+04  7.88E-02
  7.00E+04  3.08E-02
  1.00E+05  7.65E-03
  1.84E+05  1.14E-04
```

[Authors' Note: Similar CCDF distributions as above are included in the output for the other plume results, but are not shown here.]

```
1  DATE AND TIME OF RUN = MACCS2  9/05/**   17:07:08   Version 1.12, Last Modified 7/01/96 by D.
Chanin
   "ATMOS"  DESCRIPTION = MACCS2 - Random Stratified Sampling (METCOND=5)
   "EARLY"  DESCRIPTION = MACCS - TEDE

 SOURCE TERM  1 OF  1:
     Unit Ci release Pu-239 w/ nonbuoyant (open area) - YR

 RESULTS FOR A SINGLE EMERGENCY RESPONSE COHORT WITHOUT ANY WEIGHTING FRACTIONS BEING APPLIED

     COHORT 1 = NO EVACUATION OR SHELTERING
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```
  9/05/**   17:07:08    PAGE   1          PROB                             QUANTILES
PEAK      PEAK  PEAK
                                        NON-ZERO   MEAN      50TH      90TH      95TH      99TH
99.5TH     CONS      PROB  TRIAL
 CENTERLINE DOSE AT SOME DISTANCES (Sv)
  L-EFFECTIVE TOT LIF          0- .1 km   .9999  2.44E+01  8.26E+00  8.61E+01 NOT-FOUND NOT-FOUND
NOT-FOUND  1.13E+02  8.08E-02   23
  L-EFFECTIVE TOT LIF         .1- .2 km   .9999  2.43E+00  9.98E-01  8.21E+00 NOT-FOUND NOT-FOUND
NOT-FOUND  9.02E+00  8.08E-02   23
  L-EFFECTIVE TOT LIF         .2- .3 km   .9999  9.44E-01  4.32E-01  3.02E+00  3.09E+00 NOT-FOUND
NOT-FOUND  3.19E+00  1.95E-02   45
  L-EFFECTIVE TOT LIF         .3- .4 km   .9999  5.04E-01  2.48E-01  1.13E+00  1.27E+00 NOT-FOUND
NOT-FOUND  1.63E+00  1.19E-02   24
  L-EFFECTIVE TOT LIF         .4- .5 km   .9999  3.14E-01  1.64E-01  7.50E-01  8.22E-01 NOT-FOUND
NOT-FOUND  9.95E-01  1.18E-02   22
  L-EFFECTIVE TOT LIF         .5-1.0 km   .9999  1.24E-01  7.27E-02  2.87E-01  3.19E-01  3.77E-01
NOT-FOUND  3.82E-01  8.79E-03   46
  L-EFFECTIVE TOT LIF        1.0-1.5 km   .9999  4.47E-02  3.11E-02  9.70E-02  1.06E-01  1.26E-01
1.35E-01  1.38E-01  4.22E-03    7
  L-EFFECTIVE TOT LIF        1.5-2.0 km   .9999  2.27E-02  1.78E-02  4.45E-02  5.45E-02  7.04E-02
7.09E-02  7.13E-02  2.74E-03    1
  L-EFFECTIVE TOT LIF        2.0-2.5 km   .9999  1.36E-02  1.07E-02  2.80E-02  3.15E-02  3.65E-02
3.88E-02  4.37E-02  1.37E-03  501
  L-EFFECTIVE TOT LIF        2.5-3.0 km   .9999  9.14E-03  7.30E-03  1.97E-02  2.13E-02  2.47E-02
2.63E-02  2.96E-02  1.37E-03   55
  L-EFFECTIVE TOT LIF        3.0-3.5 km   .9999  6.59E-03  5.36E-03  1.25E-02  1.55E-02  2.11E-02
2.21E-02  2.44E-02  1.14E-03   91
  L-EFFECTIVE TOT LIF        3.5-4.0 km   .9999  4.94E-03  3.92E-03  1.04E-02  1.17E-02  1.54E-02
1.73E-02  2.10E-02  5.71E-04  744
  L-EFFECTIVE TOT LIF        4.0-4.5 km   .9999  3.85E-03  3.05E-03  8.07E-03  1.00E-02  1.23E-02
1.35E-02  2.05E-02  2.28E-04 7757
```

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  L-EFFECTIVE TOT LIF        4.5-5.0 km   .9999  3.10E-03  2.43E-03  6.26E-03  7.87E-03  1.10E-02
1.18E-02  1.81E-02  1.14E-04 6390
  L-EFFECTIVE TOT LIF        5.0-5.5 km   .9999  2.56E-03  2.08E-03  5.42E-03  6.84E-03  9.48E-03
1.07E-02  1.87E-02  1.14E-04 7607
  L-EFFECTIVE TOT LIF        5.5-6.0 km   .9999  2.14E-03  1.55E-03  4.16E-03  5.47E-03  8.36E-03
9.57E-03  1.60E-02  1.14E-04 8576
  L-EFFECTIVE TOT LIF        6.0-6.5 km   .9999  1.82E-03  1.33E-03  3.71E-03  4.82E-03  7.33E-03
8.75E-03  1.30E-02  3.42E-04  379
  L-EFFECTIVE TOT LIF        6.5-7.0 km   .9999  1.57E-03  1.19E-03  3.23E-03  4.18E-03  6.40E-03
7.34E-03  1.23E-02  1.14E-04 6331
  L-EFFECTIVE TOT LIF        7.0-7.5 km   .9999  1.37E-03  1.09E-03  2.73E-03  3.54E-03  5.92E-03
7.08E-03  1.11E-02  1.14E-04  213
  L-EFFECTIVE TOT LIF        7.5-8.0 km   .9999  1.20E-03  1.01E-03  2.45E-03  3.17E-03  5.17E-03
6.25E-03  1.17E-02  1.14E-04 2853
  L-EFFECTIVE TOT LIF       8.0-10.0 km   .9999  9.07E-04  7.43E-04  1.85E-03  2.42E-03  4.01E-03
4.90E-03  7.60E-03  1.14E-04 7681
```

```
 PEAK DOSE FOUND ON SPATIAL GRID (Sv)
  L-EFFECTIVE                  0- .1 km   .9999  2.38E+01  8.15E+00  8.37E+01 NOT-FOUND NOT-FOUND
NOT-FOUND  1.09E+02  8.08E-02   23
  L-EFFECTIVE                 .1- .2 km   .9999  2.36E+00  9.89E-01  7.93E+00 NOT-FOUND NOT-FOUND
NOT-FOUND  8.67E+00  8.08E-02   23
  L-EFFECTIVE                 .2- .3 km   .9999  9.15E-01  4.20E-01  3.00E+00  3.03E+00 NOT-FOUND
NOT-FOUND  3.06E+00  1.95E-02   45
  L-EFFECTIVE                 .3- .4 km   .9999  4.88E-01  2.44E-01  1.12E+00  1.24E+00 NOT-FOUND
NOT-FOUND  1.56E+00  1.19E-02   24
  L-EFFECTIVE                 .4- .5 km   .9999  3.04E-01  1.61E-01  7.43E-01  8.03E-01 NOT-FOUND
NOT-FOUND  9.47E-01  1.18E-02   22
  L-EFFECTIVE                 .5-1.0 km   .9999  1.19E-01  7.20E-02  2.82E-01  3.14E-01  3.58E-01
NOT-FOUND  3.62E-01  8.79E-03   46
  L-EFFECTIVE                1.0-1.5 km   .9999  4.31E-02  3.09E-02  9.14E-02  1.03E-01  1.20E-01
1.28E-01  1.30E-01  4.22E-03    7
  L-EFFECTIVE                1.5-2.0 km   .9999  2.19E-02  1.73E-02  4.24E-02  5.08E-02  5.92E-02
6.31E-02  6.68E-02  2.74E-03    1
  L-EFFECTIVE                2.0-2.5 km   .9999  1.31E-02  1.05E-02  2.57E-02  3.06E-02  3.48E-02
3.68E-02  4.09E-02  1.37E-03  501
  L-EFFECTIVE                2.5-3.0 km   .9999  8.81E-03  7.15E-03  1.79E-02  2.08E-02  2.36E-02
2.50E-02  2.78E-02  1.37E-03  912
  L-EFFECTIVE                3.0-3.5 km   .9999  6.35E-03  4.84E-03  1.13E-02  1.28E-02  1.72E-02
1.96E-02  2.35E-02  1.14E-03   91
  L-EFFECTIVE                3.5-4.0 km   .9999  4.76E-03  3.84E-03  1.02E-02  1.13E-02  1.45E-02
1.62E-02  2.02E-02  1.26E-03 1247
  L-EFFECTIVE                4.0-4.5 km   .9999  3.71E-03  2.99E-03  7.85E-03  9.79E-03  1.21E-02
1.31E-02  1.90E-02  2.28E-04 7757
  L-EFFECTIVE                4.5-5.0 km   .9999  2.99E-03  2.37E-03  5.99E-03  7.35E-03  1.04E-02
1.12E-02  1.67E-02  1.14E-04 6390
  L-EFFECTIVE                5.0-5.5 km   .9999  2.46E-03  2.01E-03  5.20E-03  6.51E-03  9.14E-03
1.03E-02  1.73E-02  1.14E-04 7607
  L-EFFECTIVE                5.5-6.0 km   .9999  2.06E-03  1.51E-03  4.05E-03  5.25E-03  7.88E-03
9.11E-03  1.48E-02  1.14E-04 8576
  L-EFFECTIVE                6.0-6.5 km   .9999  1.75E-03  1.30E-03  3.58E-03  4.63E-03  6.91E-03
8.22E-03  1.24E-02  3.42E-04  379
  L-EFFECTIVE                6.5-7.0 km   .9999  1.51E-03  1.16E-03  3.08E-03  3.88E-03  6.09E-03
7.12E-03  1.18E-02  1.14E-04 6331
  L-EFFECTIVE                7.0-7.5 km   .9999  1.32E-03  1.07E-03  2.62E-03  3.38E-03  5.46E-03
6.38E-03  1.03E-02  1.14E-04 6331
1 9/05/**   17:07:08    PAGE   2           PROB                              QUANTILES
PEAK       PEAK  PEAK
                                        NON-ZERO   MEAN      50TH      90TH      95TH      99TH
99.5TH     CONS      PROB  TRIAL
 PEAK DOSE FOUND ON SPATIAL GRID (Sv)
  L-EFFECTIVE                7.5-8.0 km   .9999  1.16E-03  9.65E-04  2.36E-03  3.05E-03  4.80E-03
5.81E-03  1.07E-02  1.14E-04 2853
  L-EFFECTIVE               8.0-10.0 km   .9999  8.74E-04  7.28E-04  1.75E-03  2.29E-03  3.74E-03
4.54E-03  7.27E-03  1.14E-04 7681

 DOSE FOUND AT (R,THETA) LOCATION (Sv)
  Compass Sector  1 (N)       .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
```

```
  Compass Sector  2 (NNE)     .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector  3 (NE)      .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector  4 (ENE)     .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector  5 (E)       .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector  6 (ESE)     .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector  7 (SE)      .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector  8 (SSE)     .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector  9 (S)       .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector 10 (SSW)     .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector 11 (SW)      .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector 12 (WSW)     .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector 13 (W)       .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector 14 (WNW)     .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector 15 (NW)      .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45
  Compass Sector 16 (NNW)     .2- .3 km   .1418  6.25E-02  0.00E+00  5.57E-02  2.07E-01  2.06E+00
3.01E+00  3.06E+00  1.22E-03   45

 Successful completion of MACCS2 was achieved!
 This job required a total of     23.113 CPU seconds

    Input processing required       .160 CPU seconds
          Simulation required     21.152 CPU seconds
   Output processing required      1.801 CPU seconds
```

Non-buoyant Plume With Building Wake

The following changes were made to the ATMOS file for the base case to model the release of non-buoyant plume with building wake effects.

```
* BUILDING HEIGHT (METERS) - FOR LIFTOFF CRITERION W/ BUOYANT PLUME (42.5 ft)
WEBUILDH001   13.
*
* INITIAL VALUE OF SIGMA-Y [METERS] DUE TO WAKE EFFECTS (=Wb/4.3, Wb=296 ft)
SIGYINIT001    21.
*
* INITIAL VALUE OF SIGMA-Z [METERS] DUE TO WAKE EFFECTS (=Hb/2.15, Hb=42.5 ft)
SIGZINIT001    6.0
```

Buoyant Plume

The following changes were made to the ATMOS file for the base case to model the release of the buoyant plume released in an open area.

```
* HEAT CONTENT OF THE RELEASE SEGMENTS (WATTS)
* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
```

```
RDPLHEAT001   5.0E+06 (for buoyant plume examples)
```

Buoyant Plume With Building Wake

The following changes were made to the ATMOS file for the base case to model the release of buoyant plume with building wake effects.

```
* BUILDING HEIGHT (METERS) - FOR LIFTOFF CRITERION W/ BUOYANT PLUME (42.5 ft)
WEBUILDH001   13.
*
* INITIAL VALUE OF SIGMA-Y [METERS] DUE TO WAKE EFFECTS (=Wb/4.3, Wb=296 ft)
SIGYINIT001    21.
*
* INITIAL VALUE OF SIGMA-Z [METERS] DUE TO WAKE EFFECTS (=Hb/2.15, Hb=42.5 ft)
SIGZINIT001    6.0
*
* HEAT CONTENT OF THE RELEASE SEGMENTS (WATTS)
* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS
RDPLHEAT001   5.0E+06 (for buoyant plume examples)
```

8.0 ACRONYMS & DEFINITIONS

Selected Terms and Definitions Used in Accident and Consequence Analysis & Software Quality Assurance

Absorbed Dose (D)- The energy absorbed by matter from ionizing radiation per unit mass of irradiated material at the place of interest in that material. The absorbed dose is expressed in units of rad (or gray) (1 rad = 0.01 gray).

Committed Dose Equivalent ($H_{T,50}$) - The dose equivalent calculated to be received by a tissue or organ over a 50-year period after the intake of a radionuclide into the body. It does not include contributions from radiation sources external to the body. Committed dose equivalent is expressed in units of rem (or sievert) (1 rem = 0.01 sievert).

Committed Effective Dose Equivalent (CEDE) - The sum of the committed dose equivalents ($H_{T,50}$) over a fifty-year period to various organs or tissues in the body, each multiplied by the appropriate weighting factor (w_T) -- that is $H_{E,50} = \Sigma\, w_T\, H_{T,50}$. CEDE is applicable to exposure from internally deposited radionuclides.

Documented Safety Analysis (DSA) – A documented analysis of the extent to which a nuclear facility can be operated safely with respect to workers, the public, and the environment, including a description of the conditions, safe boundaries, and hazard controls that provide the basis for ensuring safety. [10 CFR 830]

Gap Analysis — Evaluation of the Software Quality Assurance attributes of specific computer software against identified criteria.

Nuclear Facility — A reactor or a nonreactor nuclear facility where an activity is conducted for or on behalf of DOE and includes any related area, structure, facility, or activity to the extent necessary to ensure proper implementation of the requirements established by 10 CFR 830. [10 CFR 830]

Gray (Gy) - Systeme' International (SI) unit of absorbed dose. One gray is equal to an absorbed dose of 1 joule per kilogram. One Gy equals 100 rad.

Maximally Exposed Offsite Individual (MOI) - A theoretical offsite receptor defined to allow dose comparison with numerical offsite evaluation guides. The MOI is located at the maximum air concentration point (ground-level) at, or beyond the, DOE site boundary. The latter may occur with elevated or buoyant releases that do not land within the site boundary, but instead reach ground-level beyond the boundary (touchdown point).

Onsite Evaluation Point/Person (OEP) - A theoretical onsite receptor defined to allow dose comparison with numerical onsite evaluation guides. This point may be at a fixed distance (e.g. 100 m, 600 m, or 640 m), or located at the closest point on the facility or facility area exclusion zone. For elevated or buoyant releases that do not land within the exclusion zone, the OEP is the point beyond the exclusion zone where the maximum air concentration is located (touchdown point).

Rad - The unit of absorbed dose.

Rem - The unit of dose equivalent or effective dose equivalent. The rem is numerically equal to the absorbed dose in rad multiplied by a quality factor, distribution factor, and any other necessary modifying factor (1 rem = 0.01 sievert).

Safety Analysis and Design Software — Computer software that is not part of a structure, system, or component (SSC) but is used in the safety classification, design, and analysis of nuclear facilities to ensure

- proper accident analysis of nuclear facilities;
- proper analysis and design of safety SSCs; and
- proper identification, maintenance, and operation of safety SSCs.

Safety Analysis Software Group (SASG) — A group of technical experts formed by the Deputy Secretary in October 2000 in response to Technical Report 25 issued by the Defense Nuclear Facilities Safety Board (DNFSB). This group was responsible for determining the safety analysis and instrument and control (I&C) software needs to be fixed or replaced, establishing plans and cost estimates for remedial work, providing recommendations for permanent storage of the software and coordinating with the Nuclear Regulatory Commission on code assessment as appropriate.

Safety-Class Structures, Systems, and Components (SC SSCs) — SSCs, including portions of process systems, whose preventive and mitigative function is necessary to limit radioactive hazardous material exposure to the public, as determined from the safety analyses. [10 CFR 830]

Safety-Significant Structures, Systems, and Components (SS SSCs) — SSCs which are not designated as safety-class SSCs, but whose preventive or mitigative function is a major contributor to defense in depth and/or worker safety as determined from safety analyses. [10 CFR 830] As a general rule of thumb, SS SSC designations based on worker safety are limited to those systems, structures, or components whose failure is estimated to result in prompt worker fatalities, serious injuries, or significant radiological or chemical exposure to workers. The term serious injuries, as used in this definition, refers to medical treatment for immediately life-threatening or permanently disabling injuries (e.g., loss of eye, loss of limb). The general rule of thumb cited above is neither an evaluation guideline nor a quantitative criterion. It represents a lower threshold of concern for which an SS SSC designation may be warranted. Estimates of worker consequences for the purpose of SS SSC designation are not intended to require detailed analytical modeling. Consideration should be based on engineering judgment of possible effects and the potential added value of SS SSC designation. [DOE G 420.1-1]

Safety Software — Includes both safety system software and safety analysis and design software.

Safety Structures, Systems, and Components (SSCs) — The set of safety-class SSCs and safety-significant SSCs for a given facility. [10 CFR 830]

Safety System Software — Computer software and firmware that performs a safety system function as part of a structure, system, or component (SSC) that has been functionally classified as Safety Class (SC) or Safety Significant (SS). This also includes computer software such as human-machine interface software, network interface software, programmable logic controller (PLC) programming language software, and safety management databases that are not part of an SSC but whose operation or malfunction can directly affect SS and SC SSC function.

Sievert (Sv) - The Systeme' Internationale (SI) unit of any of the quantities expressed as dose equivalent. The dose equivalent in sievert is equal to the absorbed dose in gray multiplied by the quality factor (1 Sv = 100 rem).

Software — Computer programs, operating systems, procedures, and possibly associated documentation and data pertaining to the operation of a computer system. [IEEE Standard 610.12-1990, *IEEE Standard Glossary of Software Engineering Terminology*]

Toolbox Codes — A small number of standard computer models (codes) supporting DOE safety analysis, having widespread use, and meeting minimum qualification standards. These codes shall be sufficiently verified and validated, and as such, applicable to support 10 CFR 830 DSAs. That is to say, the analysts using these codes do not need to present additional defense as to their qualification, provided that they are sufficiently qualified to use the codes and the input parameters are valid.

Total Effective Dose Equivalent (TEDE) - the sum of the deep dose equivalent (from external exposure) and the committed effective dose equivalent (from internal exposure). Note that the TEDE is equivalent to the EDE. For purposes of compliance, deep dose equivalent to the whole body may be used as effective dose equivalent for external exposures.

Whole Body - For the purposes of external exposure, head, trunk (including male gonads), arm above and including the elbow, or legs above and including the knee.

95th Percentile Consequence - A statistical level of consequence that is exceeded no more than five percent of the time based on site-characteristic meteorology. The offsite radiological exposure basis documented in Appendix A to DOE-STD-3009-94 and based on the method described in the U.S. Nuclear Regulatory Commission Regulatory Guide 1.145 (February 1983) to define the meteorological conditions assumed to be present for consequence analysis. Given site-specific data, the 95th percentile consequence is determined from the distribution of meteorologically-based doses calculated for a postulated release to a downwind receptor location that would result in a dose that is exceeded 5% of the time (based on hourly averages). The specific meteorology or dilution factor leading to this dose consequence is a function of release elevation, distance to the receptor, and (to some degree) the release duration. This consequence level is direction-independent, i.e. averaged over all 360^{o} at the distance of interest. [See Position 3 in NRC Reg. Guide 1.145 and 5 Percent Overall Site χ/Q Value].

99.5 Percentile, Worst-Sector Consequence - A method described in the U.S. Nuclear Regulatory Commission Regulatory Guide 1.145 (February 1983) to define the meteorological conditions assumed to be present for consequence analysis. Given site-specific data, the sector 99.5th percentile meteorology is the set of meteorological conditions assumed during a postulated release to a downwind receptor location that would result in a dose that is exceeded 0.5% of the time (based on a yearly average) in one of sixteen 22.5^{o} sectors. The highest of the sixteen 22.5^{o} sectors is then defined as the 99.5 Percentile, Worst-Sector Meteorology/Consequence condition. This consequence level is then directionally based, and tends to exceed the 95th percentile consequence beyond about one mile for *most* sites.

The MOI dose consideration takes distance to the site boundary in each direction into account.

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Appendices

Appendix	Subject
A	Overview of Atmospheric Dispersion and Consequence Analysis
B	MACCS2 Software Defect Notices
C	Limited Parametric Study On MACCS/MACCS2 Treatment Of Plume Buoyancy And Wake Flow
D	Inputs and Recommendations for MACCS 1.5.11.1 Applications

APPENDIX A. OVERVIEW OF ATMOSPHERIC DISPERSION AND CONSEQUENCE ANALYSIS

Once the source term to the environment from a postulated accident condition has been calculated or estimated, the safety analyst must determine the concentration downwind to identified receptor locations. A robust safety analysis will apply a sound technical basis for predicting the transport and diffusion of the airborne plume. Often this is based on a dispersion model that applies environmental data specific to the facility and site under consideration.[12]

This section provides an overview of atmospheric dispersion methods, focusing on Gaussian methodology, and discusses radiological consequence analysis "back end". Recommendations are provided where appropriate for specific data or assumptions.

Dispersion Methodology & Summary Of DOE-STD-3009-94, Appendix A

Appendix A to DOE-STD-3009-94, Change Notice 2 (CN2), specifies an Evaluation Guideline for radiological exposure to the offsite receptor, and is to be applied in specifying SSCs (DOE, 2000). The numerical value of 25 rem is the Total Effective Dose Equivalent (TEDE). Dose estimates to be compared to the Evaluation Guideline (EG) are those received by a hypothetical maximally-exposed offsite individual (MOI) at the site boundary for an exposure period of two hours. The nominal exposure period of two hours may be extended to eight hours for release scenarios that occur over a prolonged period.

Appendix A to DOE-STD-3009-94 notes that the airborne pathway is of primary interest for nonreactor nuclear facilities. NUREG-1140 ("A Regulatory Analysis on Emergency Preparedness for Fuel Cycle and Other Radioactive Material Licenses") previously noted that, "for all materials of greatest interest for fuel cycle and other radioactive material licenses, the dose from the inhalation pathway will dominate the (overall) dose." For some types of facilities such as waste storage, the surface and groundwater pathways may be more important, but accident releases usually would be expected to develop more slowly than airborne releases.

The dose calculation references Regulatory Guide 1.145 of the Nuclear Regulatory Commission (NRC) for determination of the five percent overall site relative concentration (χ/Q, often referred to as the dilution factor) value at the exclusion area boundary (EAB). A straightline Gaussian model is to be applied with one-hour averaged χ/Q values for the entire course of plume duration for a period not to exceed eight hours. Text from Section A.3.3 of Appendix A on Dose Estimation (p. A-8 to A-9) states

> The relevant factors for dose estimation are receptor location, meteorological dispersion, and dose conversion values. . .

[12] The term dispersion is applied using the definition appearing as Footnote 2 in NRC Regulatory Guide 1.145 to encompass both transport (due to organized or mean airflow within the atmosphere) and diffusion (due to disorganized or random air motions) of the plume.

Dose Calculation Location. For the purposes of comparison to the EG, the comparison point is take to be the location of a theoretical MOI standing at the site boundary. This location can also be beyond the DOE site boundary if a buoyant or elevate plume is not at ground level at the DOE site boundary. In such cases, the calculation location is taken at the point of maximum exposure, typically where the plume reaches ground level. It is DOE practice and expectation that onsite individuals, both workers and public are protected under the Emergency Response plans and capabilities of its sites. This protection, along with implementation of defense-in-depth and worker safety philosophy, Safety Significant (SS) (and indirectly, through SC) SSC designation, and DOE's safety management programs, address onsite safety. However, an annual assessment of any changes in the site boundary and potential effects on safety SSC classification should be performed in association with the required annual update of the SAR for a facility. Privatization and site turnover initiatives may affect these determinations.

Atmospheric Dispersion. The 95th percentile of the distribution of doses to the MOI, accounting for variations in distance to the site boundary as a function of direction, is the comparison point for assessment against the EG. The method used should be consistent with the statistical treatment of calculated χ/Q values described in regulatory position 3 of NRC Regulatory Guide 1.145 for the evaluation of consequences along the exclusion area boundary. The determination of distance to the site boundary should be made in accordance with the procedure outlined in position 1.2 of Regulatory Guide 1.145. NRC Regulatory Guide 1.23 describes acceptable means of generating the meteorological data upon which dispersion is based. Accident phenomenology may be modeled assuming straight-line Gaussian dispersion characteristics, applying meteorological data representing a 1-hour average for the duration of the accident. Accident duration is defined in terms of plume passage at the location of dose calculation, for a period not to exceed 8 hours. Prolonged effects, such as resuspension, need not be modeled. The accident progression should not be defined so that the MOI is not substantially exposed (i.e., using a release rate that is specifically intended to expose the MOI to only a small fraction of the total material released, or . . .). The exposure period begins from the time the plume reaches the MOI.

For ground releases, the calculated dose equates to the centerline dose at the site boundary. For elevated, thermally buoyant, or jet releases, plume touchdown may occur beyond the site boundary. As noted in the discussion of receptor location, these cases should locate the dose calculation at the point of maximum dose beyond the site boundary, which is typically at the point of plume touchdown.

Accidents with unique dispersion characteristics, such as explosions, may be modeled using phenomenon-specific codes more accurately representing the release conditions. Discussion should be provided justifying the appropriateness of the model to the specific situation. For accident phenomena defined by weather extremes, actual meteorological condition associated with the phenomena may be used for comparison to the EG.

The guidance provided herein uses the prescriptive requirements of Appendix A as a basis, and is applicable for performing DSAs compliant with Subpart B of 10 CFR 83.

Before discussing choice of a model, the key important environmental transport values are summarized.

Atmospheric Dispersion Parameters And Statistical Bases

Most radiological source terms may be treated as neutrally buoyant. By neutrally buoyant, it is assumed that the cloud[13] of released material has approximately the same density as air. This is normally a valid assumption for radioactive releases that are gaseous in nature that contain trace amounts of very fine particulates, aerosols, and gases. As the cloud is emitted and moves downwind, it is common practice based on experimental data, to assume a Gaussian distribution in both the crosswind (lateral) and vertical directions. For continuous releases, the mean wind speed dilutes the pollutant but the downwind dispersion is negligible. As the cloud moves downwind it gets progressively larger due to lateral and vertical diffusion, and hence becomes less concentrated. If the release is of short duration (i.e., puff), the mean wind speed only acts as a transport agent and the turbulence in the downwind direction becomes more important. Accordingly, a puff is described by a three-dimension Gaussian equation.

Several meteorological parameters affect the shape and size of a neutrally buoyant cloud. These are discussed in the following sections.

Meteorological Parameters

Earlier it was noted that downwind dispersion of a radioactive plume may be thought of as a parallel process of transport and diffusion. In simplest terms, the transport term is mostly a function of wind and direction. The diffusion of the plume is due in large part to the atmospheric stability of the region of transport. The following sections discuss wind and direction and temperature profiles and their impact on conditions in the atmosphere.

Wind and Direction

Prevailing wind is a key determinant of the transport of the radioactive plume. In terms of importance to accident analysis calculations, wind is a vector quantity having both direction and magnitude. The wind speed at the height of the release determines both the initial diffusion of the pollutant and the travel time to reach a given downwind receptor. The initial diffusion and the plume travel are both directly proportional to the wind speed. It is also a factor in determining the magnitude of atmospheric stability. Atmospheric turbulence (i.e., mechanical turbulence) is generated when adjacent parcels of air move at different speeds or move in different directions. Thus, a change in wind speed with height

[13] Cloud shall mean either a continuous (plume) or short-term release (puff).

above the ground, or a variation in wind direction at a given height, causes mechanical turbulence. Mechanical turbulence is also generated when air interacts with some fixed object, such as the ground, described as roughness length, or with a building, described by aerodynamic effects such as wake and cavity.

The horizontal wind direction at the height of the release determines the direction of transport. It is a vector and therefore does not affect the magnitude of the concentration of the pollutant within the plume. The horizontal wind direction, or more commonly, wind direction, is the first moment, or average, of a series of "instantaneous" wind direction measurements. By convention, the wind direction is 180 degrees out of phase with the downwind or transport direction.

Atmospheric turbulence is directly related to the variability of wind direction. The variability of wind direction is normally expressed in terms of the standard deviation, or second moment, of a series of "instantaneous" wind direction measurements over a selected observation period, normally fifteen minutes. The standard deviation, or second moment of the horizontal wind direction, σ_θ, is commonly used to characterize atmospheric turbulence by stability classes. Alternatively, the standard deviation of the vertical wind component, σ_φ, is sometimes used as a basis to describe the category of atmospheric turbulence.

<u>Vertical Temperature Profiles</u>

In addition to wind direction variation, another technique that is used to type atmospheric turbulence is to use vertical temperature gradient measurements ($\Delta T/\Delta Z$). When a parcel of air is displaced in the vertical plane, it will expand (if rising) or contract (if sinking) to adjust its pressure to that of its surroundings. The expansion or contraction is accompanied by an adiabatic temperature change. As a parcel rises, it cools. If the surrounding air is warmer, the parcel will be heavier than its surroundings and sink back toward its original position; and its motion ceases. On the other hand, if the surrounding air is cooler, the parcel will be lighter and continue to move upward. Similarly, if the air parcel sinks, it warms up as it contracts. If the surrounding air is cooler, the parcel will be lighter and rise back toward its original position; and its motion ceases. If the surrounding air is warmer, the parcel will be heavier and continue to sink.

Thus, turbulence is suppressed if the temperature profile of the air (the so-called lapse rate) is less than adiabatic (i.e., subadiabatic), and enhanced if greater than adiabatic (i.e., superadiabatic). The adiabatic lapse rate near ground is about –10.8 °C/km (-5.4 ^{o}F/1,000 feet). Superadiabatic lapse rates are associated with unstable atmospheric conditions and labeled A, B, or C stability classes, with Class A representing the most unstable set of conditions. Subadiabatic lapse rates are associated with stable atmospheric conditions, inclusive of inversions (i.e., temperature increase with height) and labeled E, F, and G stability classes, with Class G representing the most stable conditions. Adiabatic lapse rates are associated with neutral atmospheric conditions and labeled as Class D. In practices, some sites limit the extent of classes to six, with G stability class being combined with F stability.

The vertical temperature profile, in turn, affects atmospheric turbulence. The atmospheric layer near the ground is called the mixing, or the mixed layer. During daylight, the ground heats up, warming the air near the surface. The lapse rate near the surface thus becomes superadiabatic and buoyancy-driven vertical turbulence enhances in the existing mechanical turbulence due to ground roughness and wind shear. At night, the ground cools, causing the air near the surface to cool, and the lapse rate becomes subadiabatic and frequently inverted. Buoyancy-driven vertical turbulence thus suppresses the existing mechanical turbulence due to ground roughness and wind shear. At greater heights, a few hundred to a few thousand meters in altitude, the lapse rate may change. It is common for the turbulent lower atmosphere to be capped by lapse rate that is subadiabatic so that turbulent eddies rising from below are suppressed. This layer near ground is thus called the mixed layer, for this is where turbulence in the strongest due primarily to the frictional effects of the earth's surface and the convective heat transfer from the earth's surface.

Atmospheric Stability Classes

A comprehensive treatment of atmospheric dispersion is so complex that many approximations are needed to make it tractable. Since turbulence is random and chaotic, it can not be parameterized and one must resort to empirical formulations. One early attempt to simplify the treatment of turbulence was to define atmospheric stability classes and associate a rate of lateral and vertical diffusion with each class as a function of downwind distance only. Although computations based on these stability classes provide only a rough approximation to reality, they have proved extremely useful and are still in use, although more accurate treatments are available. Wind direction variability and vertical temperature difference are the most common techniques that are employed. Wind direction variability provides the best approximation of mechanical turbulence, while vertical temperature difference approximates the buoyancy component.

The following sections provide key definitions associated with stability class and methods to discern the turbulence intensities that drive atmospheric dispersion.

<u>Stability Class</u>

The rate at which turbulence diffuses material depends upon the stability of the atmosphere. Seven stability classes (i.e., Pasquill-Gifford-Turner classes) have been defined. These classes, with the original descriptions and conditions of occurrence given by Pasquill (Turner, 1994), are:

A: <u>Extremely Unstable (Strong superadiabatic)</u>. Normally occurs during bright sunshine with relatively low wind speed (< 3 m/s).

B: <u>Moderately Unstable (Moderate superadiabatic)</u>. Normally occurs during conditions that range from bright sunshine with wind speeds in the 3 to 5 m/s range to dim sunshine with wind speeds < 2 m/s.

C: <u>Slightly Unstable (Slight superadiabatic)</u>. Normally occurs during conditions that range from bright sunshine with wind speeds in the 5 to 6 m/s range to dim sunshine with wind speed in the 2 to 3 m/s range.

D: Neutral (Adiabatic). Normally occurs with moderate to dim sunshine, cloudy conditions, and at night, with wind speeds > 3 m/s. It also occurs with very strong wind speeds on either sunny or cloudy days.

E: Slightly Stable (Slight subadiabatic with or without inversion). Normally occurs at night or early morning with some cloud cover and with wind speeds in 2 to 5 m/s range.

F: Moderately Stable (Moderate subadiabatic with inversion). Normally occurs at night or early morning with little cloud cover and with relatively low wind speeds (< 3 m/s).

G: Extremely Stable (Strong subadiabatic with inversion). Normally occurs at night or early morning with very light to nearly zero wind speed.

Unstable conditions result in rapid lateral and vertical diffusion of pollutants (i.e., wide plumes), whereas stable conditions result in slow lateral and vertical diffusion (i.e., narrow plumes). The latter will lead to higher air concentrations from ground-level releases.

Although Class A is not rare, it is not as common as Classes B through F. Class D is the most common stability class for many DOE sites. This is due to the large number of combinations that can result in Class D stability. For example, high-wind conditions and/or cloudy conditions during the day or at night are normally Class D. Classes E and F are the most common stability classes at night.

Note that the meteorological conditions used as a basis for DOE-STD-1027-92 Hazard Characterization, Attachment 1 are D stability and 4.5 m/s wind speed. This set of conditions is also used as a basis by chemical process industry for determining limits on chemical inventories, and is representative of most U.S. regions (29 CFR 1910.119).

Dispersion Conditions For Accident Analysis

In calculating plume concentrations, and subsequently consequences to the receptor, both "unfavorable" and "typical" dispersion conditions are of special interest in accident analyses. For accident analysis consideration of the offsite MOI receptor, unfavorable meteorology should be based on site data. In practice, this is the dilution factor (χ/Q) that coupled with the source term would lead to doses that are exceeded less than five percent of the time. The method should be conservative or consistent to the discussion in the NRC Regulatory Guide 1.145 (Position 3) as summarized in Appendix A to DOE-STD-3009-94, CN2. The 95th percentile of the distribution of doses to the MOI, accounting for variation in distance to the site boundary as a function of direction, is the comparison basis for assessment against the EG.

The size of the data set used in the meteorological assessments should be sufficiently large that it is representative of long-term meteorological trends at most sites. Meteorological data, qualified and meeting requirements of Regulatory Guide 1.23 (NRC 1972), available at most DOE sites should be applied that is representative of long-term trends. A five-year dataset is desirable, but a one-year data set can be applied under the right circumstances.[14] In lieu of site-specific meteorology, the accident analysis may use generally accepted, default stability and wind speed combinations, such as Class F stability and 1.0 m/s to 1.5 m/s wind speed, as an interim measure.

It should be noted that in the long run, site data is normally preferable over the default conditions for accident analysis.

For example, Hunter (1993) evaluated Savannah River Site data and found the 95th percentile conditions varied with release height, and receptor distance. For most facility MOI distances, it was determined that 95th percentile conditions were E stability and

- 1.7 m/s wind speed (release height of 0 m – 10 m)

- 2.1 m/s wind speed (20-m release height), and

- 3.0 m/s wind speed (60-m release height).

- For mitigated hazard analysis, DOE has not established guidance for evaluating the mitigated benefit of SSCs. Both median statistical basis (i.e., 50th percentile) and 95th percentile bases have been applied to determine onsite receptor doses. While other measures of "typical" could be applied, each is problematic. The mean (i.e., average) and the mode (i.e., peak) of a distribution, unlike the median, not heavily influenced by outliers (abnormally small or large values). For a bimodal distribution, which can often occur , the mean may fall between the peaks (i.e., modes) of the distribution and thus be comparatively infrequent, which could not be considered "typical". (The median could also be atypical in this sense but it has a relevant meaning.) In addition, if mode were chosen as "typical", a bimodal distribution could give two valid choices if the peaks are nearly as large.

- Evaluation of site data for determining 95th and 50th percentile conditions has historically been of two types. A Joint Frequency Distribution (JFD) sampling of site hourly data sorts *all* data from high relative concentration to low relative concentration and identifies various percentile conditions by ranking the full data set. Another basis is use of a random sampling technique in which a sample of the full data is randomly selected and then typically sorted into pre-assigned consequence bins (normally chosen to find high-consequence conditions). An example of this approach is Latin Hypercube Sampling (LHS).

[14] In Draft Regulatory Guide DG-111, this subject is discussed as follows: "The NRC staff considers five years of hourly observations to be representative of long-term trends at most sites. With sufficient justification of its representativeness, the minimum meteorological data set is one complete year (including all four seasons) of hourly observations." (NRC 2001)

- JFD sampling is usually done for a standard set of release conditions (e.g., hour duration, ground-level release). The random sampling basis is normally determined on an accident case-by-case basis. The JFD profile tends to be composed of more data points and is generally "smoother".

Gaussian Model For Neutrally Buoyant Plumes

The choice of a dispersion model depends on factors such as the phase of safety analysis, complexity of facility, complexity of the accident sequence, and site topography and its affect on environmental transport conditions. Simply put, the most comprehensive, realistic computer model is not the best choice for all safety analysis situations. In most situations, peer-reviewed engineering calculations and spreadsheet analyses employing a Gaussian atmospheric dispersion model are sufficient. Data requirements are typically less demanding than more complex models. Ultimately, the accident analysis calculation is more scrutable and technically defensible during independent review if based on the Gaussian model.

The simple, straight-line Gaussian dispersion equation is used as the basis for a majority of the models used in DOE safety analysis of accidental releases. It is the basis for radionuclide inventories defining Hazard Category 2 and 3 facilities in DOE-STD-1027-92, CN 2. And, as noted earlier, for compliance with Appendix A of DOE-STD-3009, and comparison with the EG, the Gaussian model can readily estimate time-integrated air concentrations (typical units of Ci-s/m^3 for radiological releases) at downwind locations and is recommended for most accident conditions (Figure A-1). While more sophisticated models are becoming more commonplace, especially in situations where complexities in physical or chemical properties, terrain, or nearby buildings influence the dispersion of radiological material, the data demands for these approaches may be prohibitive. However, for these situations, the basic Gaussian dispersion model can be bootstrapped to accommodate release and dispersion effects that are influenced by surface features or source term characteristics.

The user should exercise care over the distance for which the Gaussian model is applied. The American Meteorological Society (AMS) published a position paper indicating that the Gaussian model is estimated to be accurate within a factor of two for distances of 0.1 to 10 – 20 km when onsite meteorological tower data are available, and conditions are reasonably steady and horizontally homogeneous (AMS, 1978). Beyond 20 km and closer than 100 m should be considered to be order-of-magnitude estimates at best. Aerodynamic wakes, rough or urban terrain, and dispersion under very stable conditions and slow wind speeds introduce more uncertainty into the Gaussian model predictions.

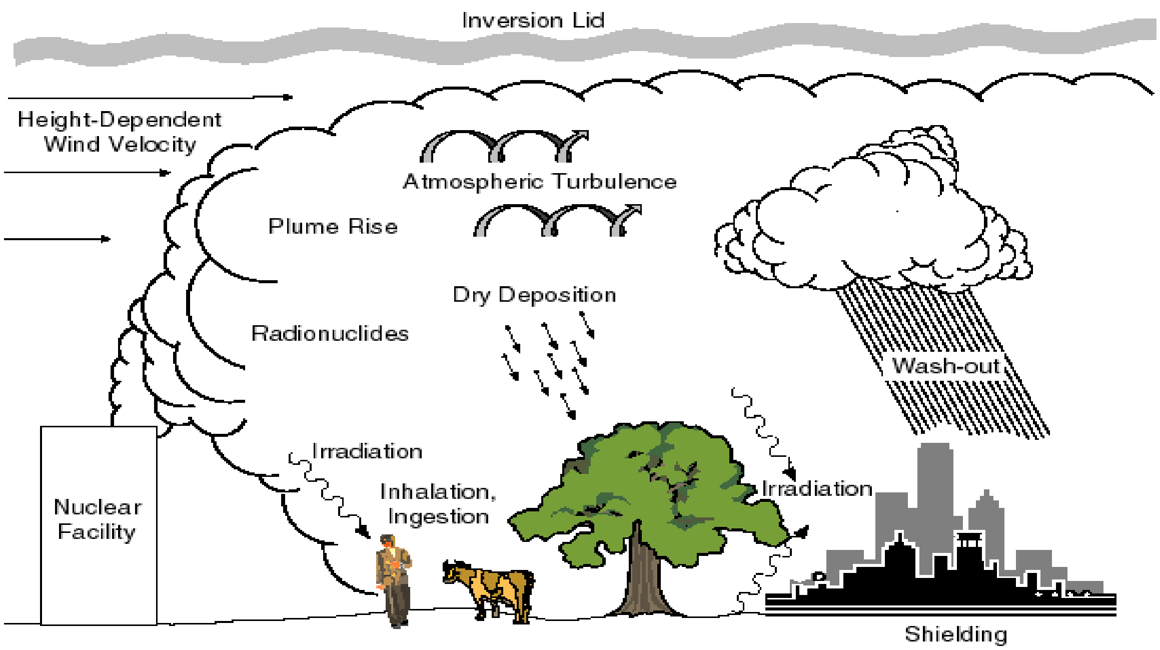

Figure A-1. Basic Processes Occurring During Accidental Release and Dose Pathways

For energetic releases, other models may be employed, as allowed under Appendix A of DOE-STD-3009-94, CN2. However, data requirements for alternative model types may preclude use to support most DSA applications. Alternative techniques have been applied to "bootstrap" a Gaussian model and thereby apply it to cases normally outside the regime of Gaussian applicability (Steele, 1998).

It is the responsibility of the analyst to make the final determination of a dispersion basis. The value of a complex, more realistic computer model with associated data demands, the requirements of the specific application, and the phase of the safety analysis must be weighed.

Recommendation: Apply the Gaussian model as a first choice. Accident phenomenology may be modeled assuming straight-line Gaussian dispersion characteristics, applying meteorological data representing a 1-hour average for the duration of the accident.

Use other special-purpose approaches as warranted for unique release situations, e.g. detonation or blast accident scenarios. Consider appropriate modifications for addressing weather extremes, such as tornado or high-wind conditions.

Basic Gaussian Equations

Intrinsic to the assumptions underlying the Gaussian approximation of atmospheric dispersion, as a plume is transported downwind, its horizontal expansion is essentially unlimited[15]. Vertical expansion is limited by the earth's surface and aloft under inversion conditions. The downward expansion of the plume must obviously stop at the ground, while upward expansion may be stopped if there is a stable layer (i.e., a "cap") at the top of the mixing layer. This cap acts as a lid to rising "thermals" of air, thus restricting the range and magnitude of vertical turbulence. The plume is often considered to "reflect" off of both the ground and the top of the mixing layer, causing the *vertical* profile to become increasingly uniform as the plume proceeds downwind.

The amount of atmospheric dilution and dispersion is usually expressed in terms of χ/Q, where χ is the concentration of the pollutant in air at some downwind location. For these formulations, χ represents either the instantaneous concentration (e.g.,Ci/m^3 or Bq/m^3) or the time-integrated concentration (e.g., $Ci\text{-}s/m^3$ or $Bq\text{-}s/m^3$), and Q is the rate of release (e.g., Ci/s or Bq/s) of the pollutant, or total source strength (e.g., Ci or Bq) of the pollutant. The units of χ/Q are s/m^3 whether the instantaneous or time-integrated releases are considered. Thus, χ/Q is the concentration of the pollutant in air at the receptor per unit source rate, or time-integrated concentration per unit source. The actual concentration of the pollutant in air at the receptor is thus the product of χ/Q and the rate of release of the pollutant.

The Gaussian plume model (Slade, 1968), when not constrained in the vertical by the ground or the top of the mixed layer, is expressed as:

$$\frac{\chi(x,y,z,h)}{Q}=\frac{1}{2\pi u\sigma_y\sigma_z}\,e^{-y^2/2\sigma_y^2}\left[e^{-(z-h)^2/2\sigma_z^2}\right] \qquad (1)$$

where *x* is the distance of the receptor downwind from the release point, *y* is the horizontal cross-wind distance of the receptor from the centerline of the plume, *z* is the distance of the receptor above the ground, *h* is the height of the plume centerline above the ground, σ_y is the standard deviation of the horizontal Gaussian distribution (i.e., the "half width"), σ_z is the standard deviation of the vertical Gaussian distribution (i.e., the "half thickness"), and *u* is the wind speed at 10 m height, the standard measurement height. The constant, 2π, is implicit in a Gaussian distribution, and is the product of lateral and vertical components each contributing $(2\pi)^{0.5}$. Note that the downwind distance *x* does not appear explicitly in this equation since downwind distance is an independent variable. The *x* dependence is implicit, as the σ_y and σ_z are functions of *x* only, for a given stability class. The wind speed (u) represents the direct dilution of the pollutant as soon as it is released into the atmosphere. The lateral and vertical Gaussian coefficients (σ_y ,σ_z) approximate the diffusion or dispersion in the atmosphere as the plume is transported downwind.

[15] Horizontal, or lateral, plume expansion may be somewhat limited by physical barriers, such as buildings and topographic obstacles, but these are normally treated as special cases.

The bracketed term in equation (1) defines the vertical distribution. If hazardous material released in the plume is reflected from the ground and from the top of the mixed layer, this term must be modified. This is done mathematically by adding multiple mirror source terms. The bracketed term in equation (1) thus is replaced with:

$$\left[e^{-(z-h)^2/2\sigma_z^2}+e^{-(z+h)^2/2\sigma_z^2}+\sum_{n=1}^{N}\left(e^{-(z-h-2nL)^2/2\sigma_z^2}+e^{-(z+h-2nL)^2/2\sigma_z^2}+e^{-(z-h+2nL)^2/2\sigma_z^2}+e^{-(z+h+2nL)^2/2\sigma_z^2}\right)\right] \quad (1a)$$

The term before the summation in the preceding equation is the ground reflection component since perfect reflection is assumed. The series of terms after the summation represent the perfect reflection of first the top of the plume and later the bottom of the plume on the top of the mixed layer. *L* represents the height of the top of the mixed layer and the summation is over the number (*N*) of reflections to be considered. The contribution of the summation term is minor, especially for distances close to the source and for larger values of L; also, the higher order terms contribute progressively less and the series is normally terminated after only a few terms. For example, in the MACCS code (Chanin, 1990), the series is terminated at $N = 5$. For a ground-level release (i.e., $h = 0$), the first two exponential terms become equivalent. Each of these terms subsequently becomes a value of one when the receptor is at ground level (i.e., $z = 0$). In these cases, the "2" in the denominator of equation (1) cancels out with the "2" in the numerator, if the summation term is ignored, as is often done. The maximum concentration occurs at plume centerline (i.e., $y = 0$). Thus, if the summation term is ignored, the Gaussian equation simplifies to a centerline condition:

$$\frac{\chi(x, y=0, z=0, h=0)}{Q}=\frac{1}{\pi u \sigma_y \sigma_z} \quad (2)$$

Strictly speaking, the numerator in the above expression is slightly greater than one because of the contribution of the summation term. Equation (2), which is now only a function of downwind distance of the receptor, is often used for the MOI, as the plume centerline concentration represents a conservative value.

Similarly, a puff model using a Gaussian formulation may be used for instantaneous or near-instantaneous releases of hazardous material

$$\chi(x, y, z; H)=\frac{Q_T}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \quad (3)$$

where:

Q_T = total source term [Ci]

σ_x = longitudinal dispersion coefficient, representing the standard deviation of the concentration distribution in the downwind axis direction [m] (AIChE 1996).

The horizontal and vertical dispersion coefficients, σ_Y and σ_Z, required in the Gaussian dispersion equation are obtained either from site-specific meteorological measurements (standard deviations of wind angles) or indirectly through estimating an atmospheric stability class for which standard dispersion coefficients have been established. If the necessary meteorological measurements are not available, several methods for determining stability class may be used. The differences between puff and plume dispersion handled with the Gaussian dispersion equation should be taken into account when applying the model. Methods for calculating puff dispersion coefficients have been addressed by Turner (1970), Gifford (1977), and Hanna (1982).

Extreme Weather Conditions

Section A.3 of Appendix A to DOE-STD-3009-94, CN2, indicates, "For accident phenomena defined by weather extremes, actual meteorological conditions associated with the phenomena may be used for comparison to the EG". A common weather extreme that is frequently addressed in many DSAs is that due to tornadoes.

The accident analysis should at minimum consider two periods for subsequent exposure evaluation: (1) that due to meteorological conditions from the tornado impact or strike itself; and (2) a second, prolonged period. The latter period would account for aerodynamic re-entrainment and resuspension acting to transport radiological material from the facility into the environment. The first period would be modeled with a design basis accident dilution factor (Ψ/Q) designated for a specific class tornado and applied for the distance from the facility to the receptor. The second period is modeled using a standard consequence model for an exposure period of no longer than eight hours, to be consistent with the time period specification discussed in Appendix A to DOE-STD-3009-94, CN2.

For the initial strike period, the appropriate Fujita scale should be applied. For most safety analysis this is either Fujita - 2 (F2) or F3. Figure A-2 shows the maximum time-integrated ground-level centerline air concentration (s/m^3) vs. downwind distance (km) for different mean translational speeds of the F2 tornado (Weber and Hunter, 1996). The consequence analysis should pick a maximum Ψ/Q for the assumed translational speed. For example, the translational speed of 7.5 m/s leads to a maximum air concentration at approximately three kilometers. This exposure should be added to that obtained for the MOI distance using the standard 95^{th} percentile condition to estimate the full exposure due to the event.

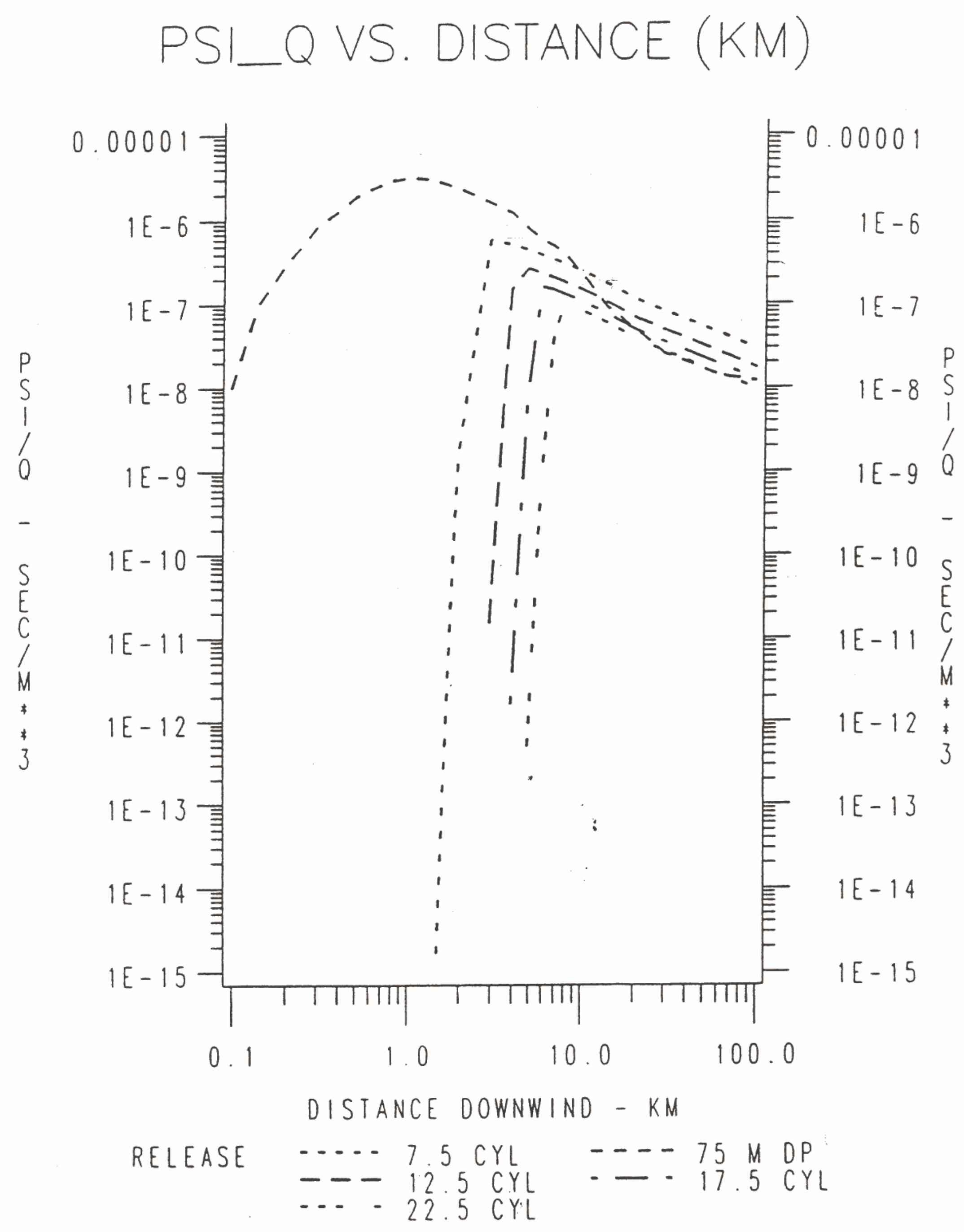

Figure A-2. The maximum time-integrated ground-level centerline air concentration (s/m^3) versus downwind distance (km) for different mean translational speeds from 7.5m/s to 22.5 m/s. The downdraft speed is 10 m/s and the height of the cylindrical mesocyclone is 3500 m (from Weber and Hunter, 1996).

Mixing Layer Height

For an evaluation of χ/Q that includes reflections from the ground and the top of the mixing layer, an estimate of the depth of the mixing layer is required. This height varies throughout the day and throughout the seasons. During clear nights, when inversions are present, the mixed layer is relatively low, while during sunny days the mixing layer is much higher. The magnitude of these heights can be obtained from balloon soundings or from remote sensing techniques, such as acoustic or radar soundings. In the absence of such data, regional tables can be consulted, such as those of Holzworth (1972).

Recommendation: Base mixing layer height on seasonal averages and day/night time of day. Apply archived site or laboratory meteorological data. If this is not applicable, use regional data as default input values.

Dispersion Parameters

Many schemes have been proposed for establishing the magnitudes of σ_y and σ_z. Most of these are based on empirical curve fitting of data that were taken during experiments over flat grassland (Haugen, 1959). One commonly used curve-fitting method is that of Tadmor and Gur (1969), in which each σ is expressed as a power law:

$$\sigma = a\,x^b + c \tag{4}$$

where a, b, and c are empirical constants, given in Table A-1 as used in the MACCS/MACCS2 code; the units of x and σ are meters. In MACCS, the c term of σ_z has been set to zero for mathematical convenience, which has required an adjustment to the a and b values.

Table A-1. Fitting Constants for σy and σz - Tadmor and Gur (as used in MACCS code)

Curve Fitting Constant	ATMOSPHERIC STABILITY CLASS					
	A	B	C	D	E	F
a_y	0.3658	0.2751	0.2089	0.1474	0.1046	0.0722
a_z	0.00025	0.0019	0.2	0.3	0.4	0.2
b_y	0.9031	0.9031	0.9031	0.9031	0.9031	0.9031
b_z	2.125	1.6021	0.8543	0.6532	0.6021	0.6020
c_y	0.0	0.0	0.0	0.0	0.0	0.0
c_z	0.0	0.0	0.0	0.0	0.0	0.0

Another commonly used curve-fitting method is that of Briggs (1973), for which each σ is expressed as

$$\sigma = a\,x(1 + bx)^{-1/2} \tag{5}$$

where *a* and *b* are constants, given in Table A-2.

Table A-2. Fitting Constants for σ_y and σ_z from Briggs

Curve Fitting Constant	ATMOSPHERIC STABILITY CLASS					
	A	B	C	D	E	F
	Open-Country Conditions					
a_y	0.22	0.16	0.11	0.08	0.06	0.04
a_z	0.20	0.12	0.08	0.06	0.03	0.016
b_y	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
b_z	0	0	0.0002	0.0015	0.0003	0.0003
	Urban Conditions					
a_y	0.32	0.32	0.22	0.16	0.11	0.11
a_z	0.24	0.24	0.20	0.14	0.08	0.08
b_y	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
b_z	0.001	0.001	0	0.0003	0.00015	0.00015

The most commonly used curves are the Pasquill-Gifford curves based on measurements at Project Prairie Grass in the mid-1950s. They are found in Slade (1968), and are based on three-minute averaging times. An empirical formula derived the Pasquill-Gifford parameters has the following form for σ_y and σ_z , and is based on work published by Yuan (1993), where

$$\sigma_y(x) = (0.000246\,\sigma_\theta^2 + 0.00576\,\sigma_\theta + 0.066)\,x^{0.9031}$$

and (6)

$$\sigma_z(x) = a\,x^b + c.$$

Coefficients and constants for various downwind distances and stability classes are given in Table A-3. The Tadmor-Gur and Briggs formulations, as well as others, give results that are nearly the same for some ranges and stability classes. However, they may differ by a factor of two or more for other ranges/classes. The coefficients given in the above tables, and in other Gaussian models, are based on fitting curves to observational data of plumes released over flat grassland. In the case of the Briggs model, an adjustment for urban conditions has also been made. The Pasquill-Gifford formulations also specify different coefficients for different ranges of distance. It should be noted that the data base underlying the empirical curve fits is valid for distances between 100 m and 1,000 m.

For distances less than about 100 m, these coefficients generally do not provide a good fit to the observations and the models are generally considered approximate. This is due to the fact that Gaussian models, with the underlying assumption of steady-state, do not perform well in the near-field.

In practice, the concentration at close-in receptor distances is frequently influenced by the physical presence of the facility from which the plume is released, as well as neighboring structures. Often, building wake effects are important for these smaller distances but the above coefficients ignore the enhancement of vertical turbulence from wake effects, down washing into the cavity behind the building, as well as recirculation. These effects can influence concentrations, and building geometry correction factors are often applied.

Recommendation: Consult with the laboratory or site meteorology organization responsible for recording and maintaining site data, and request a best-fit set of dispersion parameters for the region of transport applicable to the analysis. As a default, apply Tadmor-Gur, Briggs, or Pasquill-Gifford dispersion parameter sets, based on site-specific and surface roughness characteristics.

Table A-3. Pasquill-Gifford Dispersion Coefficients (Eimutis, 1972)

	Coefficients				
Applicable Distance, m	Stability Class	σ_θ	a	b	c
x > 1,000	A	25	0.00024	2.094	-9.6
	B	20	0.055	1.098	2.0
	C	15	0.113	0.911	0.0
	D	10	1.26	0.516	-13.0
	E	5	6.73	0.305	-34.0
	F	1.5	18.05	0.18	-48.6
100< x <1,000	A	25	0.00066	1.941	9.27
	B	20	0.0382	1.149	3.3
	C	15	0.113	0.911	0.0
	D	10	0.222	0.725	-1.7
	E	5	0.211	0.678	-1.3
	F	1.5	0.086	0.74	-0.35
x<100	A	25	0.192	0.936	0.0
	B	20	0.156	0.922	0.0
	C	15	0.116	0.905	0.0
	D	10	0.079	0.881	0.0
	E	5	0.063	0.871	0.0
	F	1.5	0.053	0.814	0.0

Special Gaussian Modeling Considerations

Plume Meander

The above expressions are for short-duration clouds released over relatively smooth terrain. However, as time passes after the initial release, larger sized eddies, mostly in the horizontal direction, may affect the cloud. Shifts in wind direction become likely with time increases since the start of release, and the cloud will tend to change direction, or meander. The meander factor is especially important for the longer duration releases. For a receptor that remains immersed in the plume for some time, meandering effectively widens the plume (i.e., increases horizontal dispersion) and thus decreases χ/Q. One formulation of the plume meander factor[16], the one used in MACCS (Chanin, 1990), but initially attributed to Gifford (1975) is

$$\textit{meander factor} = (\textit{plume duration} / \textit{time base})^n \tag{7}$$

where the time base is typically 10 minutes and the exponent n is 0.2 for plume duration of one hour or less and 0.25 for greater duration. The σ_y is increased by this meander factor and accordingly, the plume-centerline χ/Q would accordingly be reduced by this factor. The plume meander factor is never allowed to be less than one, and the experimental basis is limited to periods no longer than 100 hours.

Example: For a two hour release and a time base of ten minutes, the plume meander factor is [(2 hr) (60 min/hr) /10 min]$^{0.25}$ = 1.86.

An alternative formulation (NRC 1980) is

$$\textit{meander factor} = (2 \times \textit{plume duration})^{1/3} \tag{8}$$

where the plume duration is in hours (minimum of 0.5 hours). This gives results similar, but not identical, to those shown in equation (7).

A different type, and larger meander factor occurs under conditions that are very close to adverse meteorology for ground-level releases (i.e., very stable conditions with light wind speeds). Under such conditions, large eddies are present in the stably stratified atmosphere which augment the magnitude of the lateral turbulence. This theoretical effect was first empirically determined from tracer studies performed in the mid-1970s. After careful review of the results of the tracer study, the Nuclear Regulatory Commission (NRC) incorporated this meander factor in Regulatory Guide 1.145 (NRC 1983), and acknowledged it in several of their atmospheric dispersion models. The Regulatory Guide does not advise using this factor for relatively higher stability classes (A, B, and C).

The embedded equations in these models can simply be described by an augmentation of the lateral turbulence:

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[16] The meander factor is also called the plume expansion factor.

$\Sigma_y = M\sigma_y$ (9)

where Σ_y is the augmented lateral turbulence, and M is the meander factor.

The value of M increases for more stable conditions (i.e., from E to G stability class) and as wind speeds approach calm. This is exactly opposite to the aerodynamic building wake factor that is very small under these meteorological conditions, but increases significantly as the wind speeds increase and the stability class becomes neutral or slightly unstable.

Recommendation: Apply the Gifford model for recalibrating the time basis of the set of dispersion parameters to the release duration of interest.

Surface Roughness

Surface roughness affects the magnitude of mostly vertical turbulence, and hence, vertical atmospheric dispersion. The rougher the surface that the release passes over, the larger the turbulent eddies that are formed when the plume encounters the earth's surface. If the terrain is not smooth, which is frequently the case, a linear scaling factor needs to be introduced to increase the effective value of σ_z. A common approach to quantifying the "roughness" factor, is based on AMS (1977) and is usually expressed as:

$$\textit{roughness factor} = (z_1/z_0)^{0.2} \quad (z_1 \geq z_0) \tag{10}$$

where z_1 is the roughness length of the terrain over which the plume is passing and z_0 is the comparison standard length, normally taken as 3 cm, which represents the roughness factor associated with flat terrain. The roughness factor cannot be less than unity. Because σ_z is increased by the roughness factor, the plume-centerline χ/Q is proportionally reduced by this amount. For grasslands, the roughness length is estimated to be 10 cm. In this case, the roughness factor is $(10/3)^{0.2} = 1.27$. For terrain that includes grasslands, trees, mountains, and cities, the average roughness length commonly applied ranges from 30 cm to 100 cm. For example, if it were about 24 cm, the roughness factor would be 1.52. (Note that in the Briggs formulation of σ_y and σ_z, this roughness factor is already taken into account in that different coefficients are used for open-country and urban terrain.). McElroy and Pooler first developed "urban" dispersion coefficients in the 1960's (1968). As a rough rule of thumb, the vertical dispersion increases by one stability class for urban areas (i.e., an atmospheric condition resulting in F stability in rural environments becomes E stability in urban environments).

Recommendation: Apply a roughness correction to adjust the vertical dispersion parameterization for the region of transport based recommendations from the American Meteorological Society (1977).

Depletion Processes

While atmospheric dispersion processes are the major types affecting cloud concentration, others exist that can both remove both gases and particulates from the cloud and reinsert other radioactive species back into the atmosphere. The removal processes are dry deposition, which results from gravitation settling and fallout of material from the plume, and wet deposition, or precipitation scavenging. Reinsertion of material back into the atmosphere is termed resuspension and will be discussed in more detail in the next section. These mass transfer processes are very important in determining the ultimate fate of small respirable particulates.

Dry Deposition

The physical characteristics of particulate and aerosol radionuclide species will tend to remove this component from a released cloud. Two common models for removal are the source model and the surface model. The source model is computationally simple, in which the rate at which material in the cloud are deposited to the ground as the product of the ground level concentration of the materials, and the dry deposition velocity of the material (Chamberlain, 1953). The approach uniformly depletes the cloud. However, this treatment does not perturb the normal distribution of the concentration in the vertical direction, an assumption that is valid during neutral or unstable atmospheric conditions.

Another approach is the surface depletion method. It is computationally more complex, and depletes the source primarily at the cloud/earth interface. Use of the surface model changes the source material distribution in the cloud.

The parameterization of dry deposition processes is usually accomplished by the use of a deposition velocity. Deposition velocity (v_d) is a mass-transfer boundary condition at the atmosphere-ground surface interface in atmospheric dispersion and transport models. The deposition velocity is defined as a deposition flux (F_d) divided by the airborne concentration of radioactive material (χ):

$$v_d = F_d/\chi \tag{11}$$

In reality, the deposition velocity is a function of the particle size. The larger the particle, the larger its deposition velocity up to the Stokes velocity limit. From various field experiments conducted over the years, dry deposition velocities range from 0.001 – 180 cm/s for particulates, while for gases it ranges from 0.002 – 26 cm/s.

Dispersion models such as MACCS permit the treatment of particle sizes and assign different deposition velocities to each of user-prescribed particle size bins. The challenge facing the analyst is to assign radioactive material into these bins that has been generated under accident conditions. More than fifty variables exist that can influence the magnitude of the rate of dry deposition removal. These are categorized into micrometeorological, depositing material, and surface variable categories.

Typically, simplifying assumptions are made, based on radionuclide species, chemical form, and whether the emitted radioactive material is filtered or non-filtered. For noble gases and tritiated hydrogen gas (HT), no deposition should be modeled. For filtered particulate releases, the deposition velocity is assumed to 0.001 m/s. This dry deposition velocity corresponds to a particle with an approximate aerodynamic equivalent diameter (AED) of 0.2 μm to 0.4 μm (Sehemel, 1978). For unfiltered particulate releases, such as through cracks and open breaches assumed in the accident conditions, the deposition velocity is assumed to 0.01 m/s. This dry deposition velocity corresponds to a particle with an approximate aerodynamic equivalent diameter (AED) of 2 μm to 4 μm. Tritium oxide is normally taken to have a deposition velocity of 0.005 m/s (Fallon, 1982 and Sweet, 1984).

Wet deposition through precipitation, depletes the plume to some degree. This phenomenon is difficult to parameterize due to its dependency on cloud physics variables which themselves vary over time and space. All types of precipitation (i.e., rain, snow, hail), passing through the plume will collect particulates and also scavenge soluble gases. Wet deposition can be approximated by the following correction factor to a dispersion model:

$$D_w = \exp(-\nu x/u) \qquad (12)$$

where D_w represents the wet deposition and ν represents a washout coefficient (s^{-1}), which itself is a complex function of precipitation particle size spectrum, precipitation rate, radioactive or hazardous chemical particle size distribution, and the solubility of the effluent. As previously, x is the downwind distance of the plume centerline from its release point, and u is the wind speed. Families of empirical curves have been developed for various rainfall rates (mm/h) to estimate the washout coefficient. This procedure is made more complex by the spatial variability of the rainfall. Frequently, rainfall rates vary significantly within a rainfall event, and different washout coefficients may need to be applied to various segments of the plume as it travels to the receptor.

Wet deposition is not modeled in consequence calculations for either the MOI receptor, or the onsite receptors supporting Mitigated Hazard Analysis. While not applicable to deterministic safety analysis, it is usually credited as part of a site's historical data patterns in probabilistic safety assessments (PSAs).

In addition to these mass-transfer processes, in-growth and decay of radioactive releases constantly occur during the transport and dispersion process. The process of in-growth and decay of radioactive isotopes in the plume is a function of the travel time and the half-life of each specific radionuclide that is present in the plume. In practice, this effect is appreciable with radioisotopes of half-life on the same order or shorter than the time to reach the receptor under consideration. For non-reactor facilities, inadvertent criticality would be the primary accident type for which this factor is important.

Decay changes to the population of parent nuclide can be represented by the following factor:

$$A_i = A_i(t)/A_0 = \exp -(\lambda_\iota t) = \exp -(\lambda_\iota x/u) \qquad (13)$$

Where A_i represents the relative decrease, i.e., Activity at time t, relative to activity at time 0, or $A_i(t)/A_0$, through decay of the i^{th} radionuclide species, λ_ι is the half-life of the i^{th} radionuclide species, and the time is represented by the components x, the downwind distance, and u, the mean wind speed. In this case t = 0 at the time of release into the environment.

Recommendation: Either the source or surface model for depletion may be used in accident analysis. Do not model dry deposition for noble gases or tritium gas (HT or T_2). For filtered particulate releases, the deposition velocity can be taken as 0.001 m/s. For unfiltered releases, the deposition velocity is 0.01 m/s. Tritium oxide (HTO or T_2O) has been characterized with a deposition characteristic of 0.005 m/s. Do not credit wet deposition for DSA accident conditions. Account for decay and in-growth if the initial radionuclides involved at the start of the accident condition have half-lives shorter than the travel time to the receptor.

Resuspension

Deposition addresses mass-transfer from the plume to the ground surface. Resuspension processes are essentially the opposite of deposition processes; in which material that has already been deposited from the plume, or which has been on the ground for a period of time, is re-entrained by the wind. This re-entrainment and release from the ground of particulates is termed resuspension. The particulates are reintroduced into the atmosphere where it can be transported to a new location. While this effect can be non-negligible for DOE facilities in high-wind, environments without significant intervening vegetation, Appendix A to DOE-STD-3009-94, CN2 indicates that resuspension "need not be modeled".

Recommendation: The analyst need not explicitly account for resuspension in the dose calculation of an accident condition for a DSA.

Deposition and Reemission of Tritium

While dry deposition behavior is observed for most non-noble gas radioactive species and results in diminished plume concentrations as a function of downwind transport, tritium in particular, deposits and re-emits through mechanisms that are distinct from other radionuclides. The major biophysical processes are

- Initial settling to ground
- HT conversion to HTO by soil
- HTO uptake by plants (and partial conversion to organically-bound tritium)
- HTO re-emission from soil and plant
- Uptake by vegetation root systems
- Transport into deeper soil regions.

In evaluating tritium-containing plumes in accident analysis, it is important to recognize that tritium will tend to move in the hydrogen pool throughout the environment. For tritiated water vapor, this will mean rapid uptake depending on difference in concentration. Furthermore, re-emission of tritium from soil and vegetation will take place after plume passage. The latter phenomenon usually takes place on a time scale much longer than the initial removal from the plume (O'Kula, 2001).

Plume Rise Mechanisms

Two physical processes can vertically propel a neutrally buoyant plume to a higher level above the ground from its initial point of release. Both of these mechanisms are collectively called plume rise. The first mechanism is termed momentum plume rise, in which the velocity of the release (i.e., efflux velocity) vertically propels the plume due to the excess momentum of the release itself. Accordingly, this is termed momentum plume rise.

The other plume rise mechanism is through buoyancy. Buoyancy plume rise occurs if the temperature of the release is warmer than the ambient air. It is also important to account for stack tip downwash of the plume under high wind speed conditions and plume downwash into the wake and cavity behind the building if the release is from a vent or small stack. A brief discussion follows on both of these plume rise components, and how they interact with forces that tend to downwash. Lastly a series of equations are identified that can be integrated into an atmospheric transport and dispersion model to account for the magnitude of these effects.

Momentum Rise

The estimation of the momentum rise component requires knowledge of the efflux velocity at the point of release, the wind speed at the point of release, and the diameter of the stack from which the effluent is released from. The smaller the stack diameter the faster the efflux velocity. The efflux velocity is directed vertically, while the wind speed is directed horizontally. Therefore, the ratio of efflux velocity to wind speed determines the initial plume rise. As the plume is transported downwind, the momentum from the efflux velocity vanishes and the wind speed bends the plume over into the horizontal plane. Any additional plume rise beyond the point of release only occurs due to plume buoyancy.

Plume Rise and Entrainment Methods

NRC Regulatory Guides 1.111 and 1.145 define a “stack” release condition as one in which release occurs at or above 2.5 times the height of adjacent solid structures (NRC, 1977, 1983). Open-field, “parking lot” dispersion calculations assume non-stack releases, but with no influence of neighboring structures. Releases can be considered to be ground-level if the point of release is below the height of the facility in question and collocated buildings. The intermediate case of releases that occur in the range between 2.5 times the height of adjacent buildings and the building height, escape the building wake under certain conditions, become completely entrained into the building wake under certain conditions, or behave as a “mixture” of these types for still other conditions (NRC, 1998). Several rules of thumb are presented in this section to guide analysis under these conditions.

The NRC guidance differs moderately from the EPA Good Engineering Practice (GEP) stack height criteria. Applying the EPA criterion, the entire effluent escapes the influence of the facility structures if the stack height is 1.5 times the height of the nearest facility structure plus either the height or width of that structure, whichever is larger. For releases from structures that meet GEP stack height criteria, and under neutral or unstable stability conditions, the following equation applies:

$$h_{pr} = 1.44d \{v_e/u]^{0.667} [x/d]^{0.333} - C \qquad (14)$$

where h_{pr} is the plume rise (m), v_e is the efflux velocity (m/s), u is the wind speed (m/s), x, the downwind distance (m), and d, the diameter of the stack (m). This equation shows the relationship between the two opposing parameters, v_e, and u. C is the downwash correction factor, which is represented by:

$$C = 3[1.5 - v_e/u]d \quad (15)$$

Under stable (e.g., E-G stability classes) atmospheric conditions, the following two empirical equations are evaluated

$$hpr = 4\ [F_m/S]^{0.25} \quad (16a)$$

and

$$hpr = 1.5[S]^{-0.1666}[F_m/u]^{0.333}\ , \quad (16b)$$

and and the smaller value is chosen. In Equations 16a and 16b, the momentum flux, $F_m = v_e^2(0.5d)^2$, and the stability parameter $S = g/T[-d\theta/dz]$. For these equations, g represents gravitational acceleration (m/s^2), T is the ambient temperature (K), and $d\theta/dz$ is the potential temperature lapse rate (K/m), which is related to the actual lapse rate.

For plume rise from non-GEP stacks or building vents, empirical relationships from field studies have been developed, where the v_e/u ratio is the driving parameter. When the v_e/u ratio is >5, the vertically-directed momentum flux (i.e., escape building effects) dominates the horizontally-directed (i.e., capture building effects) wind speed, and the release is treated as elevated. This means that although the release emanated from a vent, it still will fully escape the aerodynamic effects of nearby buildings due to the high momentum flux coupled with low wind speed, and the GEP stack height equations apply. On the other end of the spectrum, when the v_e/u ratio is <1, the release is ground level and no plume rise occurs. Two intermediate cases were also developed from field studies. These are the partially entrained and the partially elevated cases and are expressed in terms of an entrainment coefficient, E_t. The entrainment coefficient is defined as the fraction of the plume entrained in the wake and cavity of the building.

Partially Entrained: For cases where the v_e/u ratio is less than 5, but greater than 1.5, a portion of the plume is entrained and the remainder of the plume remains elevated. An entrainment coefficient can be calculated for this case as follows:

$$E_t = 0.30 - 0.06v_e/u \quad (17)$$

Partially Elevated: For cases where the v_e/u ratio is greater than or equal to 1, but less than or equal to 1.5, an entrainment coefficient can be calculated for this case as follows:

$$E_t = 2.58 - 1.58v_e/u \quad (18)$$

In both of these cases, the elevated portion of the plume is subject to plume rise, while the entrained portion of the plume is downwashed to ground level. Building wake effects are discussed in more detail in a later section.

Buoyancy Rise

Buoyancy effects usually arise if significant sensible heat is contained in the cloud being released. For nonreactor DOE facilities, the primary sources of these cloud types are through postulated explosion or fire events. The estimation of the buoyancy component requires knowledge of the effluent and ambient temperatures at the point of release. If the effluent temperature is higher, positive (i.e., upward) buoyancy occurs, while for a cold or dense cloud, negative buoyancy will occur. The latter condition is normally associated with certain types of chemical releases, more so than for radiological releases. The stability class of the atmosphere is also a very important parameter to account for, as it affects the magnitude of the buoyancy plume rise.

Buoyancy rise is usually calculated in two steps. The first is the initial rise and is dependent on the stability class. The second one is the gradual rise and is independent of stability class. The larger of the two is then selected as representative.

Initial Plume Rise: For stability classes A – D, and buoyancy fluxes less than 55 m^4/s^3, the plume rise is given by (Briggs 1971)

$$\Delta h = 21.425\ F_b^{\ 3/4}\ u^{-1} \tag{19}$$

where F_b is the buoyancy flux, and is evaluated from

$$F_B = gQ_h/\pi\ C_p\ \rho_a\ T_a \tag{19a}$$

with units of [m^4/s^3]. In this equation, g is the gravitational acceleration, C_p is the specific heat of effluent gases, ρ_a is the density of air, and T_a is the ambient air temperature.

For fluxes greater than 55 m^4/s^3, the plume rise is given by

$$\Delta h = 38.71\ F_b^{\ 3/5}\ u^{-1}. \tag{20}$$

For stability classes E - G, the plume rise is given by (Randerson 1984)

$$\Delta h = 2.6\ \ [F_b/(u\ S)]^{\ 1/3}\ . \tag{21}$$

In calm conditions, a better approximation is provided by

$$\Delta h = 4\ \ F_b^{\ 1/4}\ S^{3/8}\ . \tag{22}$$

In Equations 21 and 22, S is a stability parameter with units of inverse time squared (t^{-2}), and is defined in Volume 2 of Chanin et al. (1990).

Gradual Plume Rise: The second portion of plume rise, gradual plume rise, is applicable to unstable to neutral conditions and can be calculated from

$$\Delta h = 1.6\ F_b^{\ 1/3}\ x^{2/3}\ u^{-1}. \tag{23}$$

The buoyancy flux from a fire is $F_b = 8.79 \times 10^{-6}\ \Omega$, where Ω is the rate of release of sensible energy in watts (W).

MACCS applies Equation 23 for stability classes A – D, and Equation 21 for E and F stability classes. Several methods are used in MACCS and MACCS2 to cap the height of the plume rise, such as: (1) reaches 300 F_b/u^3 (Briggs 1975); (2) when the plume centerline has reached the height of the top of the mixing layer; or (3) when one hour has elapsed. The Briggs model is based on data obtained from industrial stacks, and assumes negligible stack radius leading to the environment.

Another model is that from Mills (1987). It is based on an area (pool) fire and is more correct for facility accident analysis where the assumed fire has compromised or breached an area in the facility. The Mills method adjusts the Briggs effective release height to a lower value using

$$H_{Mills} = \{ (H_{Briggs})^3 + (R/\gamma)^3 \}^{1/3} - R/\gamma \quad \text{where} \tag{24}$$

where H_{Brigg} = effective release height estimated with the Briggs approach

R = radius of burning pool

G = entrainment coefficient for buoyant plume rise.

An area or full facility fire event would fall in this category.

Several significant issues exist in modeling a fire event in accident analysis and the ensuing release into the environment. These include

- Sensible heat released
- Fire plume history
- Radiological material involvement in the fire.

Sensible heat – The fraction of the heat of combustion that is not radiated is available to cause a temperature increase in the air and other gases emitted in the plume. This energy is sensible heat and will act to effectively increase the height of release. The radiated fraction can vary with the nature of the fire, but a typical value is ~0.3, implying a sensible heat release of 0.7. However, for indoor fires in complex facilities, the fraction can vary with heat being radiated to structures (walls and ceilings) rather than being available for heating of air and other gases escaping into the environment.

Fire plume history – Another uncertainty that exists is the temporal nature of the fire. For the same amount of radiological material released, short duration fires will lead to larger dose than longer fires due to less crosswind meander.

Radiological material involvement – Depending on facility type and location of radiological hazards with respect to the combustible loading, the fire may have a radiological component that is evenly distributed in time, localized to certain intervals, or some combination. The radioactive release history may not match up in time with the sensible heat release.

Thus fires represent complex phenomenology that can demand an inordinate level of precision relative to the purpose of accident analysis. While MACCS and other codes allow use of an effective height model based on sensible heat released, the uncertainties in fire duration, sensible heat, and radiological material involvement introduce a significant burden to the analyst to defend. The outcome of an even a successful defense to this level of detail may be difficult to interpret against the requirements of the accident analysis process.

Recommendation(s):

External (outdoor) fires: Determine the sensible heat fraction for well-defined fires. Credit only sensible heat fraction for the thermal buoyancy effect. Assume shortest duration consistent with fire sequence definition.

Internal (indoor fires: Assume no sensible heat release for release to environment. Assume shortest duration consistent with fire sequence definition.

If the source term analysis can defend the amount of sensible energy, the temporal history, and the spatial distribution, then this phenomenon may be modeled in the consequence analysis. If this cannot be defended adequately, then the source term from fire should be estimated using recommended five-factor methodology, and the consequent environmental model should assume a short duration fire, occurring as a ground-level release.

Building Wake Effects

As shown in an earlier section, releases from vents and small stacks can be entrained behind a building into its cavity due to the aerodynamic effect of the building on the wind field in which the release occurs. Figure A-3 depicts the wake and cavity zones downwind of a nuclear facility. The downwind direction is x, the facility height is H_B, and A_B is the projected cross-sectional area of the building most influencing the flow of the plume. For most bounding, screening purposes, A_B may be assumed to be the surface area of the largest wall of the building nearest the receptor. To a first approximation, the extent of the cavity zone may be taken to be approximately a downwind distance of 2.5 $A_B^{0.5}$. Similarly, the wake zone may extend to roughly ten times $A_B^{0.5}$.

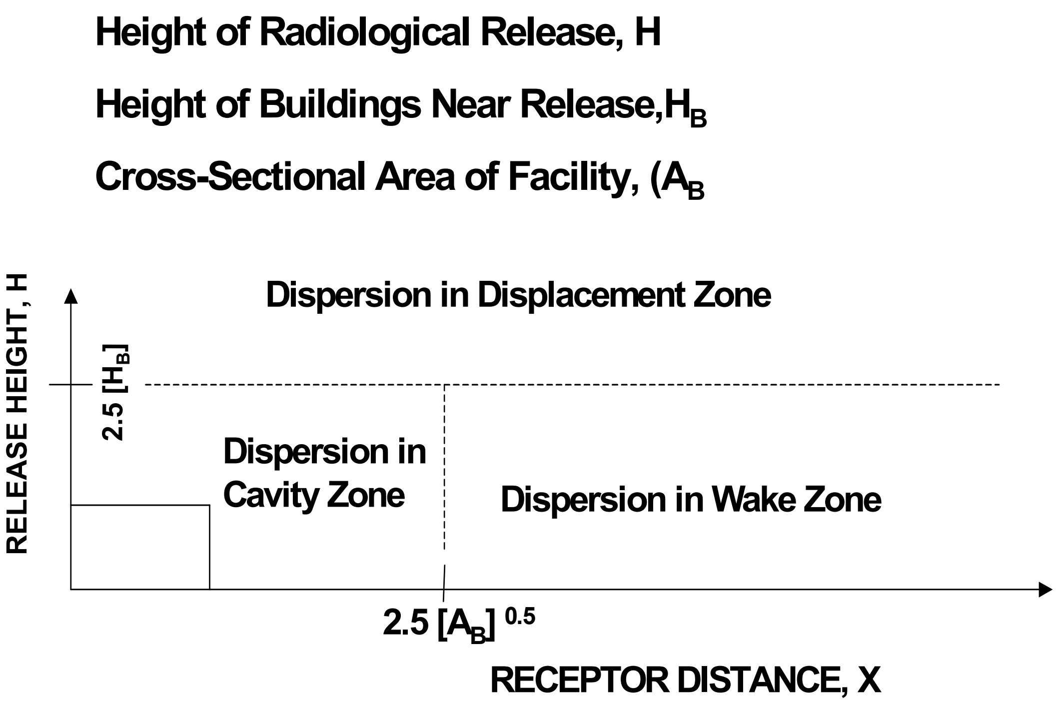

Figure A-3. Cavity and Wake Zones downwind of a Building Structure (Constant Wind Direction from Left to Right).

In order to account for aerodynamic effects of the building, the ground level dilution factor equation is modified

$$\chi/Q = (u\ [\pi\sigma_y\sigma_z + cA])^{-1} \tag{25}$$

where c is the building shape factor, usually taken to be 0.5, A is the smallest cross-sectional area of the building, u is the 10-meter height wind speed and the σ_z is corrected for the wake effect.

This formulation is to be applied in the context of NRC Regulatory Guide 1.145 for non-stack releases, e.g., vent and other building penetrations (NRC 1983). Building wake effects tend to be appreciable occur under windy conditions, while the plume meander effects (discussed earlier) are more likely under light wind conditions.

An approximate form for the wake zone concentration of airborne release from a "squat" (length and width are > height) facility, up to a receptor distance of 10 building heights ($10H_B$) is given by Turner (1970),

$$\chi/Q \approx 1/\{u\ \pi\ \sigma'_y\ \sigma'_z\} \tag{26}$$

where $\sigma'_y = 0.35\ h_w + 0.067(x - 3\ H_B)$
$\sigma'_z = 0.7\ h_w + 0.067(x - 3\ H_B)$,
$h_w = 0.866\ [(\text{Facility Length})^2 + (\text{Facility Width})^2]$.

The dispersion parameters for this condition are those found in EPA (1995b),and the distance, x, is measured from the facility center.

For screening purposes, several empirical formulas are available for the cavity and wake zone concentrations. A suggested set is found in NCRP (1996).

MACCS/MACCS2 Building Wake and Plume Liftoff

In assessing the capabilities of MACCS and MACCS2 for releases into building wakes, both codes assume initial crosswind and vertical dimensions of the plume are increased through mixing with ambient air caused by the turbulent wake. The dimensions are based on user input for the initial plume dispersion parameters in the lateral (σ_{y0}) and vertical (σ_{z0}) directions, and adjust the initial plume to (width)/4.3 and (height)/2.15, respectively.

Both MACCS and MACCS2 apply a simple approach for determining escape of a buoyant plume from its point of release. It is based on a liftoff criterion that states the plume rise will occur for wind speeds at the release height below a critical wind speed value, u_c, determined by (Briggs, 1973)

$$u_c = \{9.09\ (8.79 \times 10^{-6}\ (\text{Sensible Heat Release Rate (W)}))/\text{Facility Height}\}^{0.33} \qquad (27)$$

and will be entrained for wind speeds above u_c. The limitation with this approach is that although the plume is not allowed to rise, the code does not simulate mixing in the cavity behavior nor plume downwash. The only change is to increase plume dimensions to the extent discussed earlier (Lombardi, 1998).

The MACCS2 User's Guide recommends that the code not be applied for estimating doses at distances less than 0.5 km from laboratory or industrial-scale facilities (Chanin and Young, 1998). This is acknowledging the large degree of uncertainty in the modeling of building effects on plume release.

Recommendation: Use of open field, ground-level release conditions in the dispersion model, minimizing or eliminating the influence of nearby buildings will be bounding *in most cases.* In the case of receptor(s) within a downwind distance influenced by facility or neighboring structures, the MACCS/MACCS2 model should be used with caution. Apply appropriate scaling factor for the dilution factor and resulting doses based on receptor position in the cavity or building wake regions.

A parametric study is reported in Appendix C of this document to show the combined effects of buoyancy and building wakes on ground-level, plume-centerline χ/Q predictions by MACCS for two different wind speed conditions.

Radiological Consequences

This section provides guidance to the safety analyst regarding evaluation of radiological doses and health risks. It discusses the different types of radiation and the effect radiation can have on the human body, its organs, and its tissues. The factors that must be considered in estimating the dose a receptor may receive following the atmospheric release of radioactive material are covered in detail. Finally, the health risks associated with radiological doses and the standards for radiation protection, in terms of allowed dose or air concentration, are discussed.

Radiological doses can arise from exposure to clouds of radioactive material and fallout from the cloud, and from exposure to prompt (direct) radiation from a criticality. The modes of exposure include:

- inhalation of radioactive material (particulates and gases) in a cloud,
- inhalation of particulates from fallout that have been resuspended by traffic or by wind,
- ingestion of food products and water contaminated by fallout from the cloud,
- gamma radiation from the plume (cloudshine)[17],
- gamma radiation from particulates deposited on the ground from fallout (groundshine),
- skin contamination from fallout, and
- prompt (direct) radiation from a criticality.

Of especial concern to many DOE non-reactor facilities are inadvertent criticality events and exposure to actinide particulates. In the case of a criticality, doses arise from both the plume of fission products that may be released and from the prompt radiation. The primary contributor to dose from a criticality plume is cloudshine, although actinide particulates can also be important for an unfiltered release. Prompt radiation from a criticality is of concern only for workers located near the accident site. The distance of concern for prompt radiation depends upon the size of the criticality (number of fissions) and the amount of shielding (as from concrete walls) between the worker and the site of the criticality. On the other hand, for actinide exposure, inhalation of plutonium particulates is the primary radiological concern; cloudshine, groundshine, skin contamination, and ingestion doses are insignificant in comparison (Peterson, 1993). Inhalation of enriched uranium particulates is of lesser concern and inhalation of depleted uranium particulates are trivial by comparison (Peterson, 1995). For uranium, chemical toxicity is normally of greater concern than is the radioactivity.

[17] Cloudshine also may contain a contribution from beta radiation and its attendant *bremsstrahlung* (discussed below), but this is normally minor compared to the gamma radiation.

Types of Radiation

Four types of radiation are important in accident analysis for DOE nuclear facilities: alpha (α), beta (β), gamma (γ), and neutron. The α, β, and γ radiations are emitted from atomic nuclei during radioactive disintegration (or decay) of the nucleus. The neutron radiation is emitted when a nucleus fissions (breaks into fragments), such as during an inadvertent criticality[18]. Alpha particles are energetic (fast-moving) helium nuclei - consisting of two protons and two neutrons, with a charge of +2[19]. Beta particles are energetic electrons, of charge -1, or positrons, of charge +1 - they have a mass about 0.01% that of the alpha particle. Gamma radiation consists electromagnetic waves, or photons - gamma rays have energy similar to that of X-rays, and, being photons, have neither charge nor mass. Gamma radiation typically accompanies alpha and beta radiation. Neutron radiation consists of energetic neutrons. Neutrons are particles with zero charge and mass similar to that of protons, that is, about 25% of the mass of alpha particles. When radiation strikes an organ or tissue of the body, they can deposit some or all of their energy, causing damage. The manner of energy deposition varies with the type of radiation. Some types of radiation, principally alpha and beta, deposit energy primarily by ionization. Upon striking an atom, an electron is stripped off, and the atom is said to be ionized. The two charged particles thus formed – the electron and the ion – are referred to as an ion-pair. The electron that is stripped off the atom may be sufficiently energetic that it can cause further ionization. The amount of ionization created depends upon the mass, charge, and energy of the particle. Particulate radiation (α, β, and neutron) can also deposit their energy through the dissociation of molecules and through elastic scattering, which causes heating

Alpha-decay energy is typically on the order of several MeV (mega-electron volts)[20]. For example, plutonium, uranium, and americium all emit alpha particles with energies on the order of 5 MeV. Because an alpha particle is doubly charged and massive, it can ionize many atoms that it may encounter. For example, an alpha particle traveling through air will create on the order of 50,000 ion pairs for each centimeter it travels. Because it creates so much ionization, it deposits its energy quickly, and penetrates only a short distance into a tissue.

Beta-decay energy is typically on the order of tens of keV to a few MeV. For example, the beta-decay energy of ^{241}Pu is 21 keV. During beta decay, the emitted electron (or positron) is accompanied by a neutrino (or anti-neutrino), with which is shares the energy. The beta-decay energy is the sum of the energies of the electron and neutrino. Thus, for ^{241}Pu, the <u>maximum</u> energy the electron can have is 21 keV; normally, it will have only ~ 1/3 of this. Because the beta particle is singly charged and not very

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[18] Neutrons can also be produced through (α,n) reactions, in which an alpha particle strikes the nucleus of an atom, causing the emission of a neutron. This is generally not important for dose calculations as the additional dose from the neutron radiation is balanced by the decreased dose from the lost alpha particle.

[19] The basic unit of charge is that of the electron, but with a reversal of sign. The charge of an electron is -1.60×10^{-19} coulomb.

[20] An electron volt is the kinetic energy of an electron after being accelerated through an electric potential difference of one volt. It is equal to 1.60×10^{-19} joule.

massive, it cannot create nearly the amount of ionization as can an alpha particle. For example, a beta particle traveling through air will create on the order of 100 ion pairs for each centimeter it travels. In addition to causing ionization, beta particles also can be scattered elastically by atomic electrons. Because a beta particle doesn't lose its energy as rapidly as does an alpha particle, and because of elastic scattering, it can penetrate more deeply into tissue. However, it travels an irregular path in tissue because of elastic scattering. This gives rise to the emission of electromagnetic radiation called *bremsstrahlung* (German for "braking radiation"), which in turn can deposit its energy in the surrounding tissue.

The energy of a gamma ray is typically on the order of tens of keV to a few MeV. For example, the energy of one of the (several possible) gamma rays that accompanies the alpha decay of ^{239}Pu is 52 keV. A gamma photon will typically create only about one ion-pair per centimeter in air. A gamma photon can also lose its energy through Compton scattering from electrons and even from interactions with the nucleus of an atom, although the latter are minor in comparison with photoionization and Compton scattering. Gamma radiation is capable of penetrating deeply into the human body.

The energy of a fission neutron is typically on the order of a few keV to about 10 MeV. Because the neutron has no charge, it will not create many ion-pairs. It loses it energy primarily through elastic scattering. However, it can also cause nuclear transformations, especially when it has slowed (through elastic scattering) and become a "thermal" neutron. These nuclear transformations can lead to the emission of other radiation, such as α and γ. Neutron absorption through nuclear transformation is primarily by hydrogen and nitrogen in the body. Elastic scattering of neutrons is primarily by the hydrogen in the body. Like gamma radiation, neutron radiation is very penetrating.

Radioactivity

The *Système International d'Unités* (SI) unit of radioactivity, or simply *activity*, is the *becquerel* (*Bq*). It is equal to one *disintegration per second* (*dps*). The more commonly used, or traditional, unit of activity is the *curie* (*Ci*), and is equal to

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq.} \tag{28.a}$$

This unit was derived from the activity of radium. The activity of one gram of ^{226}Ra was originally defined as one *Ci*. (Modern measurements, however, show that the activity of one gram of ^{226}Ra is slightly less than one *Ci*.) Conversely,

$$1 \text{ Bq} = 2.7 \times 10^{-11} \text{ Ci.} \tag{28.b}$$

The activity per unit mass is called *specific activity* and is measured in units such as *Bq/k*g or *Ci/g*. Thus, the specific activity of ^{226}Ra was originally defined as one *Ci/g*. The specific activity of a mixture of radionuclides is the sum, over all the radionuclides in the mixture, of the products of specific activities and mass fractions.

The activity of a sample of any given radionuclide decreases exponentially with time, providing it is not being created by the decay of another radionuclide. If *N* is the number of atoms of a specific type of radionuclide in a sample of material, the change in this number, *dN*, in a small interval of time, *dt*, is proportional to *N* and to *dt*. This is written

$$dN = -\lambda N dt \tag{29}$$

where the negative sign is needed to show that *N* decreases with increasing time. The constant of proportionality, λ, is called the decay (or transformation) constant and is measured in inverse time units, such as s^{-1}. The disintegration rate, or activity (*A*), is given by

$$A = -dN / dt = \lambda N \tag{30}$$

The solution to equation (29) is

$$N = N_0 e^{-\lambda t} \tag{31}$$

where N_0 is the number of atoms at time $t = 0$. Thus, equation (30) can be written

$$A = A_0 e^{-\lambda t} \qquad (31)$$

where $A_0 = \lambda N_0$ is the activity at time $t=0$.

Because the decay is exponential, the time interval to decrease the number of atoms in a sample by a given factor is a constant. For example, the time to decrease by a factor of two, called the half-life ($t_{½}$), is obtained by inverting equation (31):

$$t_{½} = - (1/\lambda) \ln (½ N_0 / N_0) = (1/\lambda) \ln (2) = 0.693 / \lambda. \tag{32}$$

The half-life of ^{239}Pu, for example, is 2.44×10^4 years and that of ^{235}U is 7.1×10^8 years. The specific activity of ^{235}U is therefore about 3×10^4 times smaller than that of ^{239}Pu, which is the reason it doesn't present as great a radiological hazard as ^{239}Pu for a given amount of material.

Effects of Radiation on the Body

Radiation damages the body as it deposits its energy (primarily through ionization) in organs and tissues. Because alpha radiation can be stopped by the body's epithelium (outer layer of dead skin cells), it poses no external hazard to the body; rather, its hazard is through inhalation and ingestion. Beta radiation can penetrate the skin (barely) to cause some damage; beta radiation can also damage the eye. Like alpha radiation, its damage comes principally from inhalation and ingestion, although less so than from alpha radiation. Gamma radiation and neutrons, on the other hand, cause damage as they penetrate the body directly from external sources; material that emits gamma radiation and neutrons can, of course, be inhaled or ingested, but this is not the normal mode of exposure. Skin contamination from fallout causes tissue damage principally from β radiation.

Both short-term and long-term exposures are important. External radiation (from cloudshine, groundshine, skin contamination, or prompt radiation) typically gives a short-term, or even instantaneous dose, whereas internal radiation (from inhalation and ingestion) gives a long-term (committed) dose. A long-term dose can also arise from continual exposure to external radiation, as in a work place. If a radioactive particle is inhaled or ingested, it will cause damage as long as it remains in the body, because it contains many radioactive atoms that continue to disintegrate. If an organ or tissue is irradiated for an extended time, it can develop cancer or suffer other deleterious effects.

Dose Evaluation

The effects of exposure to ionizing radiation were originally defined in terms of the amount of ionization in air produced by gamma radiation and X-rays. The unit used was the *Roentgen* (*R*), now defined as the ratio $\Delta Q/\Delta m$, where ΔQ is the sum of all charges of one sign produced in air when all the electrons liberated by photons in a mass Δm of air are completely stopped in air. It is equal to 2.58×10^{-4} coulombs produced in one kg of air. This is equivalent to 1.61×10^{15} ion-pairs produced per kg of air or an energy deposited of 87.3 erg per gram of air (Turner, 1986). Absorption of 1 *R* of radiation in tissue corresponds to about 95 ergs per gram of tissue.

Today, dose is expressed as an absorbed dose, i.e., the amount of energy deposited in matter, or as an equivalent dose, a measure of damage done in tissue. The traditional unit of absorbed dose is the *rad* and is defined as 100 ergs absorbed in one gram of material, slightly greater than the *rep*. The newer (*SI*) unit is the *gray* (*Gy*) and is defined as one joule absorbed in one kilogram of material. Thus,

$$1 \text{ Gy} = 100 \text{ rad}$$

This definition applies to any type of radiation absorbed in any type of material.

The dose of most interest in accident analysis is the equivalent dose, as this is a measure of the biological damage. The amount of damage depends upon the type of radiation as well as the amount of energy absorbed. The equivalent dose, H_T, to a particular tissue *(T)* is equal to the absorbed dose, D_T, in that tissue times a radiation-weighting factor, w_R

$$H_T = w_R D_T \tag{33}$$

where w_R is a measure of the amount of damage done by the radiation.[21] If more than one type of radiation impacts the tissue, H_T is calculated by summing over all radiation types. Table A-4 gives the radiation weight factors (ICRP-60, 1991) for the four radiation types considered here.

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[21] The definitions given here are taken from the *1990 Recommendations of the International Commission on Radiological Protection* (ICRP-60, 1991). In earlier recommendations of the ICRP, the terminology was a little different. The following table gives the old and new terminology. The old terminology is still in use.

Old Terminology	New Terminology
Quality Factor	Radiation Weighting Factor
Dose Equivalent	Equivalent Dose
Committed Dose Equivalent	Committed Equivalent Dose
Effective Dose Equivalent	Effective Dose
Committed Effective Dose Equivalent	Committed Effective Dose

The effective dose is not identical to the effective dose equivalent in that the organ weighting factors are slightly different (Table 8) and the organs included in "remainder" are different. A similar statement can be made for the differences between committed effective dose and committed effective dose equivalent.

Table A-4. Radiation Weighting Factors

Type, Energy Range		Radiation Weighting Factor, w_R
Alpha	any energy	20
Beta	any energy	1
Gamma	any energy	1
Neutrons	< 10 keV	5
	10 keV to 100 keV	10
	>100 keV to 2 MeV	20
	>2 MeV to 20 MeV	10
	> 20 MeV	5

The traditional unit for equivalent dose is the *rem* (roentgen-equivalent, man). The newer (*SI*) unit is the sievert (*Sv*). The relation between them is the same as between *gray* and *rad:*

1 Sv = 100 rem.

The radiation-weighting factor is related to the stopping power of the material, expressed as *Linear Energy Transfer* (*LET*)

$$\mathrm{LET} = dE / dx \qquad (34)$$

where *dE* is the average energy locally imparted to the medium by a charged particle traversing the distance *dx*. Alpha and beta particles have high and low LET, respectively. Gamma radiation, although not a charged particle, is considered equivalent to low LET radiation. Neutrons have a moderate to high LET, depending upon their kinetic energy.

The definition of equivalent dose does not differentiate between short-term and long-term dose, or between external and internal exposure. A related term is committed equivalent dose, which is the predicted dose from internal exposures over the remaining life of the individual, normally taken to be 50 years for adults (such as workers) or 70 years for children (as in the general population); it does not include external exposures. The committed equivalent dose is thus a subset of the equivalent dose. This has led to some confusion as it has led some workers to use (incorrectly) equivalent dose exclusively for external radiation, apparently as a counterpoint to committed equivalent dose, which is used exclusively for internal radiation. A new term, total organ dose equivalent (TODE), is now used to indicate the sum of the external (short-term) and internal (committed, long-term) doses to *an organ or tissue* (CFR, 1991).

Doses are also calculated for the body as a whole. This is done by summing over all organs the product of an organ weighting factor and the equivalent dose for that organ. This sum is called the effective dose (formerly, the effective dose equivalent (EDE) – a term still used). The organ weighting factors represent the fraction of the total health risk resulting from uniform whole-body irradiation that could be attributed to that particular tissue or organ. These factors are between zero and one; their sum over all organs and tissues is one. The weighting factors for the various organs are shown in Table A-5, as taken from ICRP-60 (1991). For comparison, the ICRP-26 (1977) values are also shown, as they are still in use at many sites and laboratories.

Table A-5. Organ Weighting Factors

Organ	Organ Weighting Factor	
	ICRP-26	ICRP-60
Bladder	-	0.05
Bone Marrow (red)	0.12	0.12
Bone Surface (skeleton)	0.03	0.01
Breast	0.15	0.05
Colon	-	0.12
Esophagus	-	0.05
Gonads	0.25	0.20
Liver	-	0.05
Lung	0.12	0.12
Skin	-	0.01
Stomach	-	0.12
Thyroid	0.03	0.05
Remainder	0.30	0.05

A term similar to effective dose is committed effective dose (formerly, the committed effective dose equivalent – CEDE, a term still used), which is the predicted dose from internal exposures over the remaining life of the individual, normally taken to be 50 years for adults, or 70 years for children. However, it does not include external exposures. Committed effective dose is thus a subset of effective dose. However, as with equivalent dose *cf.* committed equivalent dose, confusion has arisen in that some workers use (incorrectly) effective dose to refer to only external radiation, because committed effective dose refers only to internal radiation. A new term, total effective dose equivalent (TEDE), is now used to indicate the sum of the external (short-term) and the internal (committed, long-term) effective doses (CFR, 1991).

Types of Dose

Doses arise from both internal and external exposures, as noted above. The internal exposures consist of inhalation (from the plume and from resuspension) and ingestion. The external exposures are from cloudshine, groundshine, skin deposition, and direct (prompt) radiation from a criticality. These are discussed individually below. See the discussion earlier in this chapter for the calculation of the amount of material that falls out from a plume; this is important for the discussions of resuspension, ingestion, groundshine, and skin deposition.

Uptake Through Inhalation

Inhalation dose from a cloud to a given organ or tissue from a given isotope (i) is the product of the amount of respirable radioactive material released (M_i), atmospheric dispersion factor (χ/Q), breathing rate (BR), and dose conversion factor (DCF_i)

$$\mathrm{Dose_i} = \mathrm{M_i} \times \chi/\mathrm{Q} \times \mathrm{BR} \times \mathrm{DCF_i} \tag{35}$$

assuming the receptor remains exposed for the duration of the plume. The total dose to the organ or tissue is the sum over all isotopes inhaled. The amount of respirable material released (M_i) is the product of the material at risk (MAR), damage ratio (DR), leakpath factor (LPF), airborne release fraction (ARF), respirable fraction (RF), and the atmospheric dispersion factor (χ/Q). The dose conversion factors are discussed below.

Breathing Rate

The breathing rates for the for various activities, as have been used in accident analyses for the past several years at many DOE sites, are given in Table A-6 (ICRP-2, 1977 and ICRP-30, 1979-82). The value used in the development of DOE-STD-1027-92 (Change Notice 1) tables is 3.5 x 10^{-4} m^3/s. ICRP-66 (1994) gives revised breathing for the "reference human"[22]. These are also listed in Table A-6. Still other breathing rates are appropriate for other individuals, such as infants, the elderly, and the infirm, and for other levels of activity (ICRP-66, 1994). The analyst needs to choose which breathing rate is appropriate for the scenario being evaluated, taking into account the possible need to be consistent with earlier analyses.

Recommendation: Based on the DOE (1998) directive, it is advised to apply the breathing rate of 3.33 x 10^{-4} m^3/s in dose calculations.

[22] The reference human is male, 30 years old, height 176 cm (5 feet, 9 inches), and weight 73 kg (161 lb).

Table A-6. "Reference Human" Breathing Rates for Various Levels of Activity

Activity Level	Breathing Rate (m^3/s)
ICRP-2, ICPR-30, DOE 1998	
Chronic	2.66×10^{-4}
Light	3.33×10^{-4}
Heavy	3.47×10^{-4}
ICRP-66	
Sleep	1.25×10^{-4}
Rest, sitting	1.50×10^{-4}
Light exercise	4.17×10^{-4}
Heavy exercise	8.33×10^{-4}

Biokinetic Model and Dose Conversion Factors

Once radioactive material enters the lungs, it begins to migrate to other parts of the body. A portion is transferred directly to the blood and another portion to the stomach. Transfer of the material directly from the lungs into the blood depends upon where in the lungs it is deposited and how soluble it is. Material is also cleared from the lungs by means of the body's mucociliary mechanism and then swallowed, thus entering the gastro-intestinal (GI) tract. The fraction (f_1) of the material that passes from the GI tract into the blood (primarily from the small intestine) depends the solubility of the material. For some radionuclides, such as iodine, the transfer to the blood is nearly complete ($f_1 = 1.0$). For others, such as plutonium, the portion transferred to the blood is much less than 1%; the remainder is excreted. Once the material enters the blood, it can be carried to any part of the body. From there, it may preferentially target a given organ or tissue, as determined by the chemical properties of the radioactive material and the nature of the organ or tissue. For example, plutonium and americium become preferentially attached to bone surface (LANL, 1995), and tritium ultimately mixes uniformly with all tissues and organs.

The residence time of a radioactive particle in the lungs depends in part upon the solubility of the material. Three broad categories have been defined, and specify a characteristic half-time for inhaled material to clear from the pulmonary region of the lung to the blood and the gastrointestinal tract (Eckerman, 1988):

- Y: Radionuclides in insoluble compounds typically remain in the lungs for a long time; these are of Solubility Class Y (for years), also called Lung Clearance Class Y.

- W: Radionuclides in moderately soluble compounds remain in the lungs for weeks; these are of Solubility Class W (for weeks), also called Lung Clearance Class W.

- D: Radionuclides in soluble compounds remain in the lungs for only a short time; these are of Solubility Class D (for days), also called Lung Clearance Class D.

According to Federal Guidance Report #11 (EPA, 1988), plutonium compounds can be Class Y (the oxides[23]) or Class W (all other Pu compounds). There are no Class D Pu compounds. Americium compounds are only Class W. Uranium compounds can be Class Y (UO_2 and U_3O_8), Class W (UO_3, UF_4, and UCl_4), or Class D (UF_6, UO_2F_2, and $UO_2(NO_3)_2$). Fission products are of all three classes. Should these compounds be involved in a fire, their chemical nature may change. For example, a plutonium salt (as in certain residues), which is class W, may change to an oxide (class Y) in a fire. However, such conversion will probably not be complete. To be conservative, it is best to assume that the resultant chemical form is the one that gives the largest dose; in the case of plutonium salts, for example, it is conservative to assume they remain class W.

In ICRP Publication 60, the lung clearance class term was dropped in favor of the term lung absorption type. Absorption types fast (F), medium (M), and slow (S) broadly correspond to older lung clearance classes of D, W, and Y (ICRP, 1990).

Dose Conversion Factors

The amount of biological damage that radioactive material may inflict on an organ or tissue is given by the Dose Conversion Factor (DCF) mentioned above. The DCFs take into account the migration of the radioisotope within the body, the decay of the radioisotope, and the formation of daughter isotopes that may be radioactive. For inhalation, this is typically expressed in units of Sv/Bq (or rem/Ci), that can be converted to Sv/g (or rem/g) by multiplying by the specific activity.

The older system of DCFs for a large number of radionuclides is given in Federal Guidance Report #11 (EPA, 1988). FGR 11 contains DCFs based on weighting factors from ICRP 26 (ICRP, 19770 and organ/tissue models documented in ICRP 30 and 48 (ICRP, 1979a to 1982c, and ICRP, 1986). The DCF values in FGR 11 are based on exposure to an adult worker and a particle size of 1.0 µm Activity Median Aerodynamic Diameter (AMAD).[24] The values are applied uniformly for all ages in the general public population and all release conditions.

ICRP Publication 68 provides updated dosimetry for radiation workers, while ICRP 72 covers the general public. Both include age specific models and parameters (ICRP, 1995). The DCFs contained in these reports are based on ICRP 1990 Recommendation on radiation protection standards in Publication 60 (ICRP, 1991a) and as well as the revised kinetic and dosimetric model of the respiratory tract in Publication 66 (ICRP, 1994). The inhalation DCFs in ICRP Publication 68 are for the CEDE and assume either 1.0 µm or 5.0 µm AMAD particle sizes. The inhalation DCFs in ICRP 72 are only for the CEDE and a 1.0 µm AMAD particle.

A combined data set is now available from the ICRP (1999) that not only provides dosimetric information for both worker and general public populations, but extends the parameter space of the

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[23] Plutonium hydroxides have subsequently been added to Class Y.

[24] The AMAD signifies that fifty percent of the activity in the aerosol is associated with particles of aerodynamic diameter greater than the AMAD.

ICRP Publications 68 and 72. The combined data gives inhalation dose coefficients for ten aerosol sizes (0.001 μm to 10 μm AMAD) as well as ingestion coefficients. Effective doses and equivalent doses for all important tissues for a range of integration times (1, 7 and 30 days, 1, 5, 10, 20, 30, and 45 years) are given, together with the dose coefficients to age 70 years.

The Nuclear Regulatory Commission and at least one NRC Agreement State have granted license amendments to allow use of the newer ICRP 68/72 dosimetry. The newer data have been approved for use at least one DOE site.

Inhalation (Resuspension)

Dose from resuspension inhalation is primarily of concern after plume passage. The ground concentration (GC_i) of a given isotope (i) under a plume can be calculated by the method discussed earlier, which also discusses resuspension factor (F_r) of this material. The resuspension inhalation dose to a given organ or tissue from this isotope is the product of the ground concentration, resuspension factor, breathing rate, and DCF_i for that organ and radionuclide.

$$\mathrm{Dose_i} = \mathrm{GC_i} \times \mathrm{F_r} \times \mathrm{BR} \times \mathrm{DCF_i} \qquad (36)$$

The total dose to the organ or tissue is the sum of the doses from all isotopes resuspended. Correction factors can also be applied, as appropriate, to account for the receptor being off-centerline (if the GC_i was calculated for plume centerline) and for shielding, such as for the receptor being indoors. Off-centerline considerations and shielding are normally of greater importance for resuspension inhalation than for plume inhalation because resuspension takes place over an extended period and the routine activities of the receptors should be taken into account. This is especially important for inhalation doses to the public. The comparative magnitude of the resuspension dose depends on the amount material deposited on the ground from the plume. If the amount is large, the resuspension inhalation dose over a period of days, weeks, or months can be as large as, or even larger than, the direct inhalation dose from the plume. For dry deposition, the size distribution of the particulates released in an accident is important; very small particles have small deposition velocities, leading to small ground concentrations. For wet deposition, particles of all sizes can be washed out by precipitation. If an accidental release of radioactive particulates occurs during a period of rain or snow, the subsequent resuspension inhalation dose will be much larger than it would be otherwise.

It is noted that the guidance in DOE-STD-3009-94, CN2, Appendix A allows the analyst to ignore resuspension.

Ingestion

Fallout of particulates from a plume may contaminate water and food supplies. The uptake of radionuclides by plants and animals, and their transfer into the food chain for humans, is a very complex process and beyond the scope of this guidebook. Several models have been developed and incorporated into computer models for atmospheric dispersion and consequence assessment. Consumption of contaminated food products is not restricted to persons living near the site of an accidental release, as the food products may transported to another location for processing, and consuming in still another location. The ingestion dose must therefore be calculated separately from the other doses (from inhalation, etc.). It is not to be added to the doses from the other modes of intake unless it is clear that the receptor for the ingestion dose is the same as the receptor for the other modes of intake.

Once the amount of radioactive material ingested has been determined, the dose can be calculated by multiplying this amount by the DCF for ingestion. Tables of ingestion DCFs for a large number of radionuclides are available from both the older FGR 11/12 series as well as the ICRP 72 series. Like the inhalation DCFs, the units of the DCFs are Sv/Bq (or rem/Ci).

For calculations supporting DSA preparation, ingestion is ignored.

Cloudshine

The amount of gamma radiation (and beta, if appropriate) received by a receptor from a plume of radioactive material depends upon the location of the receptor relative to the plume. The greatest dose would be received by a receptor in the plume centerline, of course, and dose conversion factors have been developed for such a receptor. The assumptions made in deriving these DCFs are that (1) the plume is uniform and semi-infinite ("semi" because the plume extends upward from the ground, but not downward) and (2) the receptor is standing upright on the ground. The dose received from a given radionuclide is the product of the concentration of the radionuclide and the DCF, integrated over the duration of the plume. The doses from all the radionuclides must then be summed. Cloudshine DCFs are expressed in units of (Sv-m^3)/(Bq-s).

The cloudshine doses calculated using the DCFs from Federal Guidance Report #12 are conservative because of the assumptions that the receptor is standing upright in a uniform, semi-infinite cloud. The plume, of course, is neither uniform nor semi-infinite, the receptor may not be at plume centerline (and the plume may even be elevated), the receptor may be sheltered, and the receptor may not be standing up. Each of these factors would tend to reduce the dose. Corrections for finite cloud size and distribution (Gaussian) and for receptor locations off-centerline are included in several computer models of atmospheric dispersion and consequence assessment. However, for typical MOI dose-to-an-individual calculations supporting DSA preparation, the effect of structural shielding is conservatively not taken into account.

Groundshine

The treatment of groundshine is similar to that of cloudshine. The amount of gamma radiation received by a receptor from radioactive material deposited on the ground (fallout) depends upon the location of receptor relative to the fallout. The greatest dose would be received by a receptor at the center of the fallout, of course, and dose conversion factors have been developed for such a receptor. The assumptions made in deriving groundshine DCFs are that (1) the material is uniformly distributed on the surface or in the soil for an infinite distance in every horizontal direction, and (2) the receptor is standing upright on the ground. The dose received from a given radionuclide is the product of the concentration of the radionuclide on (or in) the ground and the DCF, integrated over the duration of the exposure (i.e., how long the receptor is present to receive groundshine). The groundshine doses from all the radionuclides must then be summed. The concentration to be used in the calculation is either an areal concentration (Bq/m^2), if the material is only on the surface, or a volume concentration (Bq/m^3), if mixed with the soil. Groundshine DCFs are expressed in units of either (Sv-m^2)/(Bq-s) for surface contamination, or (Sv-m^3)/(Bq-s) for soil contaminated down to a specified depth.

Typically, the groundshine doses calculated using the DCFs the two data series are conservative because of the assumptions that the receptor is standing upright on a uniformly contaminated, infinite plane. The fallout, of course, is neither uniform nor infinite and the receptor may not be the middle of it. Furthermore, surface irregularities (surface roughness and uneven terrain) tend to shield the receptor, the receptor may be sheltered, and the receptor may be elevated. Each of these factors would tend to reduce the dose. Corrections for finite size and distribution of the fallout pattern, and for receptor locations off-centerline, are included in several computer models of atmospheric dispersion and consequence assessment. The safety analyst may also wish to consider additional dose reduction factors associated with sheltering or surface roughness / unevenness.

In calculating groundshine doses, the time variation of the ground concentration at the receptor's location must be considered. In the early stages of plume passage, the ground concentration is increasing, the concentration reaching a peak at the end of plume passage. Resuspension of the particulates then erodes the amount of contamination. The dose received from groundshine therefore must consider not only the exposure duration of the receptor, but also the period during which the exposure is attained. Such considerations are included in several computer models of atmospheric dispersion and consequence assessment.

Skin Deposition

Doses from skin deposition are normally of short duration (a few hours) because of decontamination of the skin. The only radionuclides of importance for skin contamination are the beta emitters. Beta particles can penetrate the surface layer of dead skin cells and damage the cells directly beneath. Experiments show that for beta radiation in the 200 keV to 2 MeV range, the absorbed dose to these cells is about 0.2 rad/s for a surface contamination of 1 Ci/m^2 (Healy, 1984). Because the radiation-weighting factor for beta radiation is one (Table A-4), this equates to a dose rate of 5.4×10^{-14} (Sv-m^2)/(Bq-s). This dose rate must then be integrated over the duration, *T*, that the material is on the skin prior to decontamination to give the skin DCF

$$\mathrm{DCF_{skin}} = 5.4\times10^{-14}\,(1 - e^{-\lambda T}) / \lambda \qquad (37)$$

The dose to the exposed skin from a given beta-emitting isotope (i) for a receptor at (or under) plume centerline is

$$\mathrm{Dose_{i,skin}} = \mathrm{AC_i} \times \mathrm{V_d} \times \mathrm{DCF_{skin}} \times \mathrm{F} \qquad (38)$$

where AC_i is the ground-level air concentration of this isotope, V_d is the deposition velocity to the skin (on the order of 1 cm/s or less, depending upon the particle size distribution), and *F* is the fraction of the plume duration that the receptor is exposed to the plume. Correction factors need to be applied for receptors off-centerline or that are sheltered. The total skin dose will be the sum of the contributions from all the beta-emitters that are deposited on the skin.

Direct (Prompt) Dose

Doses from criticalities arise from both the plume of fission products that may be released and from prompt radiation, i.e., the gamma rays and neutrons that are emitted during the brief (millisecond) energy burst(s) during the criticality spike(s). The doses from the plume of fission products are included in the discussions above and won't be repeated here.

The prompt dose depends only upon the number of fissions in the criticality, the distance to the receptor, and the amount of intervening shielding material, such as concrete. The gamma and neutron doses should be quantified using nuclear engineering principles.

Shielding is expressed in terms of the amount of intervening concrete, or the equivalent if other shielding materials are involved. In the case of gamma radiation, the dose is reduced by a factor of 2.5 for the first eight inches of concrete, a factor of 5.0 for the first foot, and a factor of 5.5 for each additional foot. For neutron radiation, the dose is reduced by a factor of 2.3 for the first eight inches of concrete, a factor of 4.6 for the first foot, and a factor of 20 for each additional foot.

Prompt dose is important for the immediate worker, i.e., one within some tens of meters from the accident, but is rarely important for persons more distant. The dose to a collocated worker at a distance of 100 m is normally small and the dose to the public is negligible.

Health Risks

The discussion in the following sections is added for completeness, because the DOE-STD-3009-94, CN2 Appendix A calculation is concluded upon calculation of individual doses.

Once doses have been calculated, the corresponding health risks can be determined. This is done by multiplying doses by stochastic risk factors. Latent Cancer Fatalities (LCFs) are the health risks of most interest. The term "latent" indicates that the estimated cancer fatalities would occur sometime in the future, within the next 50 years for adults, or the next 70 years for the general population, which includes children. One can also calculate latent cancer occurrences (fatal plus non-fatal), genetic effects, etc., but these are not normally evaluated in safety analyses. The stochastic risk factor depends upon the type of radiation and the organ considered.

High-LET Radiation

In the case of alpha emitters, such as Pu and U, the only organs of importance for cancer risk are the lungs, liver, and bone surface (Abrahamson, 1993). The stochastic risk factors for cancer fatalities for these organs are shown in Table A-7. For these three organs, the stochastic risk factors are linear and continuous. Earlier models, based on ICRP-26 (1977), used a linear-quadratic model. The new model, based on ICRP-60 (1991), is linear but may be discontinuous for some radionuclides. The Abrahamson (1993) values (Table A-7) differ from the earlier ones (ICRP-26): the lung factor is about four times larger, the bone skeleton factor is about ten times smaller, and liver is about three times smaller than the earlier values. The values in Table A-7 are for high-LET radiation (alpha particles). Table A-7 does not give the stochastic risk factor for committed effective dose, as the total cancer risk should be calculated as the sum of the individual organ cancer risks [Σ (dose × stochastic factor)]. The other organs of the body do not contribute significantly to cancer risk from exposure to alpha radiation and have been ignored.

Table A-7. Stochastic Risk Factors for Alpha-Emitters (Abrahamson, 1993)

ORGAN	RISK FACTOR *(LCF/rem)*
Bone Surface	6.0×10^{-7}
Lungs	8.0×10^{-5}
Liver	1.5×10^{-5}

Example: A calculation of committed inhalation doses to a certain receptor from a release of plutonium gives a bone-surface dose of 0.353 rem, a lung dose of 0.112 rem, and a liver dose of 0.0787 rem; the effective dose (whole body) was 0.0351 rem. (The effective dose includes contributions from all organs, not just the three mentioned here.) For this individual, the LCF risk would therefore be
$(0.353)(6.0 \times 10^{-7}) + (0.112)(8.0 \times 10^{-5}) + (0.0787)(1.5 \times 10^{-5}) = 1 \times 10^{-5}$ LCF.
This means that only one person in 10^5 would die of cancer from this exposure. Note that although the bone dose is larger than the doses to the other organs, the lung dose is more important in terms of cancer risk, as seen in this example.

<u>Low-LET Radiation</u>

For low-LET radiation (beta and gamma radiation), the latent cancer risk is normally calculated from the committed effective dose, although the individual organ cancer risks could also be summed. ICRP-60 (1991) recommends using a stochastic risk factor of 5×10^{-4} LCF/rem (5×10^{-2} LCF/Sv) for the whole population, or 4×10^{-4} LCF/rem (4×10^{-2} LCF/Sv) for adult workers, based on the committed effective dose. (The factor for the public is higher than for adult workers because the public consists of a mixture of individuals with varying degrees of resistance to hazardous materials, including children, the elderly, and the infirm. This includes the cancer risk to all organs, unlike the treatment of alpha radiation, which considers only the three organs of Table A-7 to be important for cancer risk.) This ICRP-60 recommendation has been adopted by the Environmental Protection Agency for the evaluations of Environmental Assessments (EAs) (NEPA, 1993). Had this factor been used in the above example, the LCF risk to that individual would have been $(0.0351)(5 \times 10^{-4}) = 1.75 \times 10^{-5}$ LCF, or about 75% higher than obtained from using Table A-7 data. This low-LET risk factor is not recommended for alpha-emitters (high LET).

<u>Acute Health Risks</u>

Doses received in a short period (acute doses) may cause acute health risks, if large enough. A dose from gamma or neutron radiation, such as from a criticality, is the primary concern here. Table A-8 (adapted from Turner (1986)) summarizes the health effects associated with varying levels of gamma radiation.

Table A-8. Acute Radiation Effects for Gamma Radiation

DOSE (rad)	HEALTH EFFECT
0 -25	No detectable effect
25 - 100	Some biological damage; recovery probable
100 - 300	More damage; recovery probable but not assured
300 – 600	Fatalities occur in about half the population
> 600	Death expected

An acute, whole-body, gamma-ray dose of about 450 – 500 rad would probably be fatal to about half the population within about 30 days. This dose is known as LD_{50}, sometimes called $LD_{50/30}$, where "LD" means Lethal Dose. Because gamma radiation has a radiation-weighting factor of one (Table A-4) the doses in Table A-8 could also have been labeled in rem. Presumably, neutron doses (in rem) would give similar effects.

An acute dose from inhalation of plutonium or uranium, i.e., the dose received in a few hours or days, is normally very small. All of the isotopes of plutonium and uranium have half-lives of many years; therefore, the inhalation dose received by a person during the first few days following an acute exposure via the inhalation pathway will only be a small fraction of the lifetime dose. Accordingly, an acute health effect requires a very large amount of plutonium to be released. For example, in order for a person at a distance of about 2 km from the release site to get a dose large enough to cause pneumonitis (the first prompt health effect to occur), an airborne release of about 100 kg of respirable plutonium would be required (Peterson, 1993). Such a large release is extremely unlikely. Therefore, *acute* health effects need not be considered for releases of plutonium or uranium.

Radiation Protection

Radiation protection of the worker is governed by the As Low As Reasonable Achievable (ALARA) principle. Control of internal exposure to radionuclides is based on the limitation of the sum of current and future doses from annual intake (i.e., the committed effective dose equivalent) rather than of annual dose. If it is found that limits on committed dose have been exceeded for a worker, corrective actions are needed to limit further exposure.

The primary guides for worker annual exposure are 5 rem for effective dose equivalent, 50 rem to individual organs or tissues (except the lens of the eye), and 15 rem to the lens of the eye. Two types of derived guides are used to implement this. These are the Annual Limit on Intake (ALI) and the Derived

Air Concentration (DAC). The ALI is the annual intake of a radionuclide that would result in a radiation dose to the reference man equal to the relevant primary guide. The DAC is the air concentration of a radionuclide that would result in an intake corresponding to its ALI, if breathed for a work-year (2,000 hours).

The above guidance of comparing the annual exposure limit (primary guide) with the full 50-year (or 70-year) committed effective dose received is found in several DOE and EPA documents. For dose calculations supporting DSAs, the dose should be calculated using the full fifty-year commitment, following conservative health protection and radiological practices. The newer dose conversion factor methodology and biokinetics models as described in ICRP 60, 66, and ICRP 68/72 are recommended. The older FGR guidance can be used as an alternative should local agreements still support use of the earlier dose conversion data.

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APPENDIX B. SOFTWARE DEFECT NOTIFICATIONS

MACCS2 Software Package Sandia National Laboratories	**Software Defect Notification**

1. Date: 5/26/98
2. Log Number: M2V1-12A
3. Computer Code: ☒ MACCS2 ☐ COMIDA2 ☐ FGRDCF ☐ IDCF2 ☐ DOSFAC2
4. Computer Code Version Number: Version 1.12
5. Defect Classification: ☒ Major ☐ Minor
6. Does the defect still exist? ☒ Yes ☐ No · Defect to be corrected in MACCS2 V1.13

7. Brief Description of Defect:
When multiple source terms are specified in a single calculation, that is, when the source term change case is invoked in the ATMOS input file by specifying a change record set (ref. Section 5.11 of MACCS2 User's Guide, Vol. 1, SAND97-0594, NUREG/CR-6613), certain parameters specified to be changed will be incorrectly implemented. The source term change case parameters that are involved in the defect are: PSDIST (particle size distribution by group), SIGYINIT and SIGZINIT (initial values for σ_y and σ_z), BUILDH (building height), and some of the released inventory in the fourth plume segment. The source term change case parameters that are not affected by the defect are: PLHEAT (plume heat), PLHITE (plume height), PLUDUR (plume duration), PDELAY (plume release time), REFTIM (plume reference time point), and the inventories of the first 3 plume segments.

8. Brief Description of Evaluation/Impact:
Parameters PSDIST, SIGYINIT, SIGZINIT, BUILDH, and the inventory of the 4th plume segment will be incorrectly implemented if they are specified to be changed in the source terms that follow the initial source term specification. The specified changes for these parameters are actually implemented in the previously defined source term. For example, suppose a user specifies an initial source term with 4 plume segments and then uses 5 source term change cases for a total of 6 source terms in the calculation. In each new source term the following parameters are specified to be changed: plume duration, initial σ_y and σ_z specifications, and release fractions for all 4 plume segments. The 4th plume segment inventory and the σ_y and σ_z values which will be corrupted in the first 5 source terms, all other source term parameters will be implemented correctly (the only entirely correct source term is the 6th and final one).

9. Recommendations:
Avoid using the source term change case feature in MACCS2, or only specify changes for the unaffected parameters listed in Item 7 above.

10. Expected Corrective Actions:
The defect will be corrected in the next release of MACCS2 (Version 1.13)

Julie Gregory	Julie Gregory	5/26/98
Recorded by	Signature	Date

MACCS2 Software Package Sandia National Laboratories	**Software Defect Notification**

1. Date: 5/26/98
2. Log Number: M2V1-12B
3. Computer Code: ☒ MACCS2 ☐ COMIDA2 ☐ FGRDCF ☐ IDCF2 ☐ DOSFAC2
4. Computer Code Version Number: Version 1.12
5. Defect Classification: ☒ Major ☐ Minor
6. Does the defect still exist? ☒ Yes ☐ No Defect to be corrected in MACCS2 V1.13

7. Brief Description of Defect:
When multiple (up to 3) emergency response scenarios are specified in the EARLY input file (ref. Section 6.6.1 of MACCS2 User's Guide, Vol. 1, SAND97-0594, NUREG/CR-6613), certain parameters specified in a new emergency response definition will cause errors to result in the EARLY module calculation. <u>The parameters that are involved in the defect are:</u> RESCON (resuspension concentration coefficient) and RESHAF (resuspension concentration halflife); although these two parameters are not typically used in an alternate emergency response strategy, they potentially may be used. <u>All other parameters that may be specified in an alternate emergency response do not involve the defect.</u>

8. Brief Description of Evaluation/Impact:
Specification of new values for the parameters RESCON and RESHAF in an alternate emergency response scenario in the EARLY input will result in erroneous results (not only for the alternate scenario, but for the initially specified response scenario).

9. Recommendations:
Do not define alternate emergency response scenarios that involve the parameters RESCON or RESHAF.

10. Expected Corrective Actions:
The defect will be corrected in the next release of MACCS2 (Version 1.13)

Julie Gregory	Julie Gregory	5/26/98
Recorded by	Signature	Date

APPENDIX C. LIMITED PARAMETRIC STUDY ON MACCS/MACCS2 TREATMENT OF PLUME BUOYANCY AND WAKE FLOW

A limited parametric study was performed of the models used in MACCS/MACCS2 to incorporate the effects of buoyancy and a building wake on atmospheric dispersion of plumes from an accidental release.[25] The following cases were run in the limited parametric study.

Table C-1. Cases for Limited Parametric Study on Plume Buoyancy and Wake Flow

Case Description	Atmospheric Stability Class D		SRS 50% Meteorological Conditions
	Wind Speed of 4.5 m/s	Wind Speed of 2.3 m/s	
Simple Gaussian Plume[1]	●	●	
Plume with Building Wake Effects[2]	●	●	
Buoyant Plume[3]	●	●	
Buoyant Plume with Building Wake Effects[2,3]	●	●	●

[1] Nonbuoyant plume released under open-field conditions

[2] Building has dimensions of 20-m high × 50-m wide x 50-depth

[3] Rate of sensible heat release, 10 MW

In the parametric study centerline χ/Q dilution factors for ground-level releases based on a 30-minute averaging time are calculated for each case with the assumption of no plume depletion from deposition mechanisms. Dilution factors are calculated at downwind distances of 100 m, 200 m, 500m, 1 km, 5 km, and 10 km. The critical wind speed calculated for a 20-m high facility and with concurrent 10 MW sensible heat release, using the Briggs threshold equation is 3.4 m/s (Equation (27) in Appendix A of this report).

Results for the 4.5-m/s cases are shown in Figure C-1, and results for the 2.3-m/s cases are shown in Figure C-2. The case for SRS median (50th percentile) meteorological conditions is shown in both figures and serves as a baseline case to facilitate comparisons between the two sets of results.

[25] The calculations were performed using MACCS 1.5.11.1 but similar results as presented in this appendix would be expected with MACCS2.

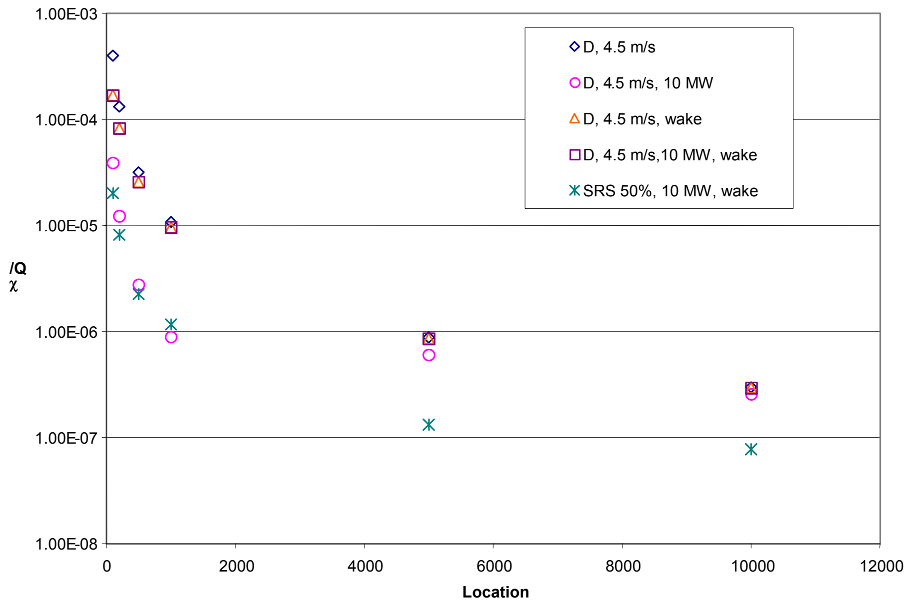

Figure C-1. MACCS results for buoyant plume with building wake effects (4.5 m/s wind speed)

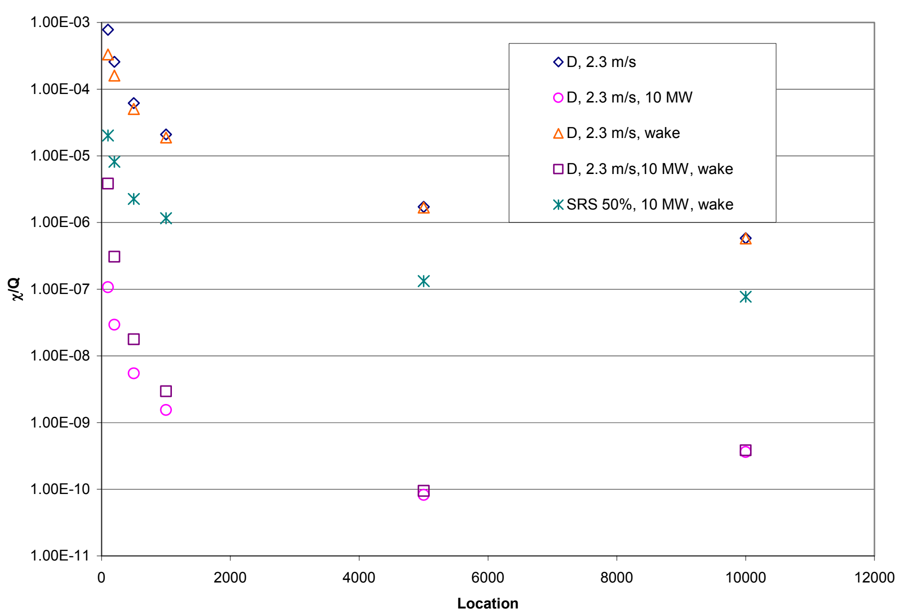

Figure C-2. MACCS results for buoyant plume with building wake effects (2.3 m/s wind speed)

General trends that are observed in both figures are as follows:

- The highest centerline χ/Q values (representing highest downwind concentrations) are calculated with the simple Gaussian plume cases. Adding buoyancy and/or wake effects reduces ground-level concentrations with respect to the simple Gaussian plume case. Buoyancy induces plume rise that results in lower ground-level concentrations. The building wake increases the initial dispersion of the plume in the horizontal and vertical directions, resulting in lower ground-level centerline concentrations. For the building dimensions used in the calculations, building-wake effects essentially become insignificant for non-buoyant plumes at distances beyond 1 km. For the 2.3-m/s and 4.5-m/s sets of results, the calculated downwind concentrations at distances of ≥1 km for the building-wake cases with the non-buoyant plumes are within 10% (slightly lower) of those for the corresponding simple Gaussian plume.

- The lowest centerline χ/Q values (representing lowest downwind concentrations) are calculated with the buoyant plume case. For the building dimensions and sensible heat rate input considered in the limited parametric analysis, the plume rise has a larger effect in reducing ground level consideration than does the building-wake effect. The explanations for why the combined effects of buoyant-plume and wake effects produce higher downwind concentrations compared to those from buoyant-plume effects alone are discussed below. Different phenomena are responsible for this trend for the two wind speeds used in the analysis.

With a wind speed of 4.5 m/s that is above the 3.4 m/s liftoff criterion, the results for the combined effects of plume buoyancy and the building wake are identical to those calculated for building-wake effects alone. MACCS uses a liftoff criterion that is based on a critical wind speed that is a function of the buoyancy flux and the building height. The buoyancy flux is directly proportional to the sensible heat rate of release as discussed in the body of this document. If wind speed is high enough, then the plume does not escape the building wake and the buoyancy has no effect. The critical wind speed (liftoff criterion) defines the maximum wind speed that will allow the buoyant plume to escape from the wake and rise as it travels downwind. Both a high sensible heat rate and small building height support a high critical wind speed. For the first two non-wake cases (D stability and 4.5 m/s wind speed), the results indicate that the 10 MW sensible heat provides about an order of magnitude lower dilution factor than without sensible heat. The effect is important close-in but grows negligibly small after 3 to 4 km. For the sensible heat rate input and building dimensions considered, because the 4.5 m/s wind speed implies that the plume is not escaping, MACCS is initializing the plume dimensions in the same manner for the wake cases regardless of whether 10 MW sensible heat is added. For the 50-m square and 20-m high facility assumed, the initial plume lateral and vertical dimensions are σ_{y0} = 50 m/4.3 = 11.6 m, and σ_{z0} = 20 m/2.15 = 9.3 m.

The wind speed of 2.3 m/s is below the 3.4 m/s critical wind speed, and the results of Figure C-2 show that plume buoyancy is now factored into the results. Here the downwind concentrations for the combined effects of plume buoyancy and the building wake are substantially lower than those calculated for building-wake effects alone. They are also slightly higher than those calculated for plume-buoyancy effects alone for distances in the first 1000 m to 2000 m. For the case combining the effects of plume buoyancy and the building wake, the plume rises but the increased dispersion from the building wake increases the vertical spread of the plume and increases concentrations in the portion of the plume that contacts the ground. Thus, the ground-level concentrations are higher compared to those from a buoyant plume released in an open field for the first 2000 meters of plume travel. After this distance the dilution factors are about the same.

With D stability, and plume rise "allowed", the model applied in MACCS is Equation (23) of Appendix A of this report. Applying this formulation indicates that plume rise would continue until a distance of approximately 5820 m at which point the plume has grown to the mixing layer height (~1000 m). From that distance to points farther downwind the dilution factors for the thermally buoyant cases (with and without wake effects) start increasing and in time will be similar to the non-buoyant cases.

For additional insights, comparisons can be made between the 2.3-m/s and 4.5-m/s wind speed results for similar cases. First to be examined are the cases involving nonbuoyant plumes, namely, the simple Gaussian plume and plume with building wake effects. For both of these the 2.3-m/s wind speed concentrations are approximately twice as large as the corresponding 4.5-m/s wind speed concentrations. This trend reflects the inverse proportionality of downwind concentration with respect to wind speed in the Gaussian model as shown in Equations (1) and (2) from Appendix A of this report. In the other two cases that involve buoyant plumes, the trend is drastically different. For buoyant plumes, the 4.5-m/s wind speed yields higher concentrations that are more than a magnitude higher than the corresponding 2.3-m/s wind speed concentrations. The plume rise from buoyancy is more pronounced under lower wind speed conditions.

Similar comparisons have been reported previously. One study compared the relative capabilities for MACCS2 and an updated WAKE model from HGSYSTEM/UF_6 for a large facility release, with and without wake effects and plume buoyancy (Lombardi, 1998). It was concluded that MACCS was limited in its treatment of close-in, wake-impacted releases, and also in predicting all or nothing entrainment based on ambient wind speed alone.

The authors of this report recommend MACCS results be carefully reviewed and checked with independent calculations for cases where sensible heat and building wake influence effects are included. It is important to be aware that the combined effects of buoyant-plume and wake effects generally produce higher downwind concentrations compared to those from buoyant-plume effects alone. Only well-defined fires (time sequence, spatial definition, and sensible heat release) should be modeled with any atmospheric code, especially in terms of the initial plume behavior. Furthermore, the MACCS-predicted consequences for the first several hundred meters of plume travel should be applied cautiously.

APPENDIX D. INPUTS AND RECOMMENDATIONS FOR MACCS 1.5.11.1 APPLICATIONS

Section 4.0 of the main body of the report provides guidance for specifying inputs when using the MACCS2 computer code. This appendix provides parallel guidance for specifying inputs when using the earlier version of the code, namely, MACCS 1.5.11.1 (referred to as simply MACCS in the discussion below).

General Notes

For MACCS, all values not in quotes must be in UPPER case.

Quote marks should be single straight quote marks (i.e. 'input value') not smart quotes marks (i.e. ‘input value’)

The MACCS naming convention for input parameters is as follows:

Characters one and two indicate the date block

Characters three to eight indicate the variable name

Characters nine to eleven indicate the line of data being entered (there must always be eleven characters in the input parameter name)

The MACCS naming convention for user requested output is as follows:

Characters one to five indicate the output type

Characters six to eleven indicate either the number of requested input or the specific output requested

The discussion in this section is based on the MACCS User’s Guide (Chanin, 1990) and the MACCS Model Description (Volumes 1 and 2, Chanin, 1990). For each section of input, page-specific references to the MACCS User’s Guide (NUREG/CR-4691, Vol. 1 – page X-Y) is provided. This will allow the DOE safety analyst to review the original report from the SNL code developer to check directly a specific variable.

ATMOS Input File

The particular ATMOS input file commented upon here is used because it is one of the sample files (e.g., IN1A.INP) supplied with the software from RSICC.

This section of the document addresses variables that may be changed during a normal execution of MACCS for input into a safety basis document or must be selected by the user for a specific location. If a variable is not explicitly mentioned, it need not be changed.

Identification Data Block (RI) *NUREG/CR-4691, Vol. 1 – p. 12*

Variable ATNAM1 (ATMOS input file identifier line)
Line within MACCS IN1A.INP sample file:

```
RIATNAM1001  'IN1A.INP, SURRY, SAMPLE PROBLEM A, ATMOS INPUT'
```

For a specific application:
Change to a descriptive title for this execution of MACCS.

Geometry Data Block (GE) *NUREG/CR-4691, Vol. 1 – p. 13*

Variable NUMRAD and SPAEND (Number of radial grid endpoints and locations of radial grid endpoints)
Lines within MACCS IN1A.INP sample file:

```
GENUMRAD001  26
*
GESPAEND001      .16       .52      1.21      1.61      2.13
GESPAEND002     3.22      4.02      4.83      5.63      8.05
GESPAEND003    11.27     16.09     20.92     25.75     32.19
GESPAEND004    40.23     48.28     64.37     80.47    112.65
GESPAEND005   160.93    241.14    321.87    563.27    804.67
GESPAEND006  1609.34
```

For a specific application:

If population data is being used, the MACCS grid supplied in the software package transmittal should be sufficient. However, distances past 80.5 km (50 miles) should be eliminated. If a consequence at a single receptor point is required, the following lines, or similar lines, may be used:

```
GENUMRAD001  35
*
GESPAEND001    0.20   0.30   0.40   0.50   0.60   0.70   0.80
GESPAEND002    0.90   1.00   1.50   2.00   2.50   3.00   3.50
GESPAEND003    4.00   4.50   5.00   5.50   6.00   6.50   7.00
GESPAEND004    7.50   8.00   8.50   9.00   9.50  10.00  10.50
GESPAEND005   11.00  11.50  12.00  12.50  15.00  20.00  30.00
```

If the location of interest is not a midpoint of two of these endpoints, the two closest to the location may be changed.

Note:

If meteorological data is sampled based on binning of like conditions, values must be included here that are within 10% of the rain interval endpoints that are specified though the RNDSTS variable of the M4 data block.

Nuclide Data Block (IS) *NUREG/CR-4691, Vol. 1 – p. 14*

Variable NUMISO (Number of radionuclides)
Line within MACCS IN1A.INP sample file:

```
ISNUMISO001 60
```

For a specific application:
Change to the number of radionuclides being released. This number must be 150 or less. If the number of radionuclides is greater than 150, either the inventory must be divided into groups with a maximum of 150 radionuclides, or only those radionuclides that contribute to the overall TEDE should be retained. A useful rule of thumb is approximately 0.1% - below which radionuclides are not considered because they contribute insignificantly to the dose.

Variable WETDEP and DRYDEP (Wet and dry deposition flags as inputted by DEPFLA)
Line within MACCS IN1A.INP sample file:

```
ISDEPFLA001    .FALSE.   .FALSE.
ISDEPFLA002    .TRUE.    .TRUE.
ISDEPFLA003    .TRUE.    .TRUE.
ISDEPFLA004    .TRUE.    .TRUE.
ISDEPFLA005    .TRUE.    .TRUE.
ISDEPFLA006    .TRUE.    .TRUE.
ISDEPFLA007    .TRUE.    .TRUE.
ISDEPFLA008    .TRUE.    .TRUE.
ISDEPFLA009    .TRUE.    .TRUE.
```

For a specific application:
For the noble gases group, both values should be set to ".FALSE." For the other groups, the first value should always be ".FALSE." indicating no wet deposition. When dry deposition is used, the second value should be set to ".TRUE."

Variable MAXGRP (Number of chemical groups)
Line within MACCS IN1A.INP sample file:

```
ISMAXGRP001 9
```

For a specific application:
This is simply the total number of groups determined above with a minimum value of 1 (all radionuclides are modeled in the same manner) and a maximum

value of 10. Typically this value will be 3 or less (group 1 – noble gases, group 2 – tritiated water vapor, and group 3 – all other radionuclides).

Variable NUCNAM, PARENT, IGROUP, and HAFLIF (Radionuclide name, parent radionuclide, chemical group, and half-life as inputted by OTPGRP)
Line within MACCS IN1A.INP sample file:

```
ISOTPGRP001     CO-58        NONE       6       6.160E+06
ISOTPGRP002     CO-60        NONE       6       1.660E+08
ISOTPGRP003     KR-85        NONE       1       3.386E+08
  .
  .
  .
ISOTPGRP060     CM-244       NONE       7       5.712E+08
```

For a specific application:
The selection of the chemical groups is based on similar release fractions and plume removal mechanisms (i.e. wet and dry deposition). For example, both noble gases and tritiated water vapor have a release fraction of 1.0, but the noble gases are not subjected to either removal mechanism while tritiated water vapor can be removed by both wet and dry deposition mechanisms. Thus, noble gases would be in one chemical group, and tritiated water vapor would be in another.

Wet Deposition Data Block (WD) *NUREG/CR-4691, Vol. 1 – p. 17*

These values should not be changed.

Dry Deposition Data Block (DD) *NUREG/CR-4691, Vol. 1 – p. 18*

Variable NPSGRP (Number of dry deposition velocity groups)
Line within MACCS IN1A.INP sample file:

```
DDNPSGRP001   1
```

For general application:
Set this value to the maximum number of dry deposition velocities groups to be used in a majority of site analyses. Typically this value will be 3 (one group will be for releases passing through a filtration system; one group will be for releases straight to environment; and one group will be for tritiated water vapor).

Variable VDEPOS (Dry deposition velocities)
Line within MACCS IN1A.INP sample file:

```
DDVDEPOS001   0.01   (VALUE SELECTED BY S. ACHARYA, NRC)
```

For general application:

Typically, the line will be:

```
DDVDEPOS001   0.001  0.005 0.010
```

The dry deposition velocity of 0.001 m/s is appropriate for releases passing through a filter before being released into the atmosphere as well as those not passing through a filter depending on release and environmental conditions. The 0.001-m/s deposition velocity is consistent with a particle with an aerodynamic equivalent diameter (AED) of 0.2 to 0.4 microns (Sehemel, 1978). The dry deposition velocity of 0.005 m/s is an approximate value for tritiated water vapor (Fallon, 1983; Sweet, 1984). The dry deposition velocity of 0.01 m/s is appropriate for unfiltered releases straight into environment and corresponds to particles with an AED between 2 to 5 microns (Sehemel, 1978).

Additional discussion on the topic was presented earlier in Appendix A, and in the NRC reference for recommended MACCS inputs (NRC, 1990b).

Dispersion Data Block (DP) *NUREG/CR-4691, Vol. 1 – p. 19*

Variable YSCALE (Scaling factor for sigma y)
Line within MACCS IN1A.INP sample file:

```
DPYSCALE001    1.
```

For a specific application:
Normally this value should not be changed. However, if a duration longer than 10 hours is absolutely needed. This value may be changed to calculate a dose from a release of up to 100 hours (the upper valid range of the model). The longer release duration correction factor is calculated by dividing the new duration in seconds by 180 seconds and raising the quotient to the 0.25 power. The release duration (variable PLUDUR in the RD data block) must be set equal to 180 seconds. If the user changes the 180-second basis, e.g. use of a new dispersion set with a ten-minute basis, then this must be reflected in the calculation.

Variable ZSCALE (Scaling factor for sigma z)
Line within MACCS IN1A.INP sample file:

```
DPZSCALE001    1.27
```

For general application:
The calculation of this variable is discussed in Appendix A under surface

roughness, and is calculated as $(z_{new}/z_{ref})^{0.2}$, where the quotient of the new and reference surface roughness length is raised to the power of 0.2 Thus, the scaling factor as a function of surface roughness length , which approximately equals one-tenth of the height of roughness obstacles (Hanna, 2002), is

Obstacle Height	30 cm	100 cm	10 m
Surface Roughness Length	3 cm	10 cm	100 cm
σz correction	1.	1.27	2.02

The surface roughness parameter is region-of-transport specific and should be changed to be consistent for the environment surrounding facility in question.

Variable CYSIGA, CYSIGB, CZSIGA, and CZSIGB (Linear and Exponential Terms for sigma y and sigma z)
Line within MACCS IN1A.INP sample file:

```
DPCYSIGA001   0.3658   0.2751   0.2089   0.1474   0.1046   0.0722
DPCYSIGB001    .9031    .9031    .9031    .9031    .9031    .9031
DPCZSIGA001   2.5E-4   1.9E-3       .2       .3       .4       .2
DPCZSIGB001    2.125   1.6021     .8543    .6532    .6021    .6020
```

For a specific application:
These values should be set once for the dispersion parameter set being applied. However, if an individual location has a specific set of linear and exponential terms for sigma y (σ_y) and sigma z (σ_z), then those values should be used.

Plume Meander Data Block (PM) *NUREG/CR-4691, Vol. 1 – p. 21*

Variable TIMBAS (Time base for the parameterization of the plume meander adjustment factor (seconds).)
Line within MACCS IN1A.INP sample file:

```
PMTIMBAS001    600.   (10 MINUTES)
```

For general application:

This value should be set once and not changed.

If the values based on the Project Prairie Grass are being used as given in the sample MACCS input, set the value to three minutes (180. s) (NRC, 1990b).

If another set of dispersion coefficients are being used, the value should be consistent with the time-basis of those experiments.

Plume Rise Data Block (PR) NUREG/CR-4691, Vol. 1 – p. 23

These values should not be changed.

Wake Effects Data Block (WE) NUREG/CR-4691, Vol. 1 – p. 24

Note: The building size may not be credited if a stack release is being modeled.

Variable BUILDW (Width of the building)
Line within MACCS IN1A.INP sample file:

```
WEBUILDW001   40.  *  SURRY
```

For a specific application:
Normally this value should be set equal to its minimum value of 1.0, and implies no credit is taken for the size of the building. If the building is credited, the width should be set equal to the average of the sides of the building. Use of this parameter will initialize the plume lateral standard deviation, σ_{y0}, to W/4.3 (Chanin, 1990).

Variable BUILDH (Height of the building)
Line within MACCS IN1A.INP sample file:

```
WEBUILDH001   50.  *  SURRY
```

For a specific application:
Normally this value should be set equal to its minimum value of 1.0, and implies no credit is taken for the size of the building. If the building is credited, the value used here is the actual height of the building, H, and the initial vertical standard deviation, σ_{z0}, will be set to H/2.15 (Chanin, 1990).

Release Description Data Block (RD) NUREG/CR-4691, Vol. 1 – p. 25

NOTE: All values in this data block may be changed using a change case.

Variable ATNAM2 (Source term identifier)
Line within MACCS IN1A.INP sample file:

```
RDATNAM2001 'SECOND DRAFT 1150, WORST CASE SOURCE TERM FOR EARLY FATALITIES'
```

For a specific application:
Change the entire character string to identify the source term.

Note:

A unique identifier must be used for each case

Variable NUMREL (Number of plume segments being released)
Line within MACCS IN1A.INP sample file:

```
RDNUMREL001          2
```

For a specific application:
Change to the number (≤ 4) of plume segments defined in the source term. If more than four plume segments are defined, the activity of consecutive source terms may be added together if they have the same release duration, release height, and sensible heat rate. The release duration of the combined plume segments is the same as the individual plume segments.

Variable REFTIM (Representative time point for each plume)
Line within MACCS IN1A.INP sample file:

```
RDREFTIM001       0.00      0.50
```

For a specific application:
The representative time point for each plume should be zero

Variable PLHEAT (Sensible heat rate of each plume segment)
Line within MACCS IN1A.INP sample file:

```
RDPLHEAT001     3.7E+6     1.7E5
```

For a specific application:

If the sensible heat rate is credited and the release mechanism is an explosion, the energy of the event can be divided by sixty seconds, as a conservative reduction. This will underpredict the sensible heat rate of the event by at least an order of magnitude as explosions are normally much less than one minute in duration.

The sensible heat option in MACCS should be applied only for well-defined fires. Credit only sensible heat fraction for the thermal buoyancy effect, and apply conservative spatial factors to account for area-type fires. Assume shortest duration consistent with fire sequence definition.

Variable PLHITE (Release height of each plume segment)

Line within MACCS IN1A.INP sample file:

```
RDPLHITE001         0.        0.
```

For a specific application:

If the release height is not defined in the given source term, this value should be set equal to zero meters for each plume segment. If the release is elevated and the release height is not at least 2.5 times the tallest collocated building height, the release height is set equal to zero.

Variable PLUDUR (Plume duration of each plume segment)

Line within MACCS IN1A.INP sample file:

```
RDPLUDUR001      1800.    22000.
```

For a specific application:

If the release duration is not defined in the given source term, this value should be set equal to 180 seconds (or the value of TIMBAS defined in the expansion factor data block) for each plume segment. The value range on this parameter is from the TIMBAS value (180 seconds) to 36000 seconds (10 hours). Release duration of longer than 10 hours are calculated by setting the duration of the plume segment to TIMBAS and applying the appropriate YSCALE factor

Variable PDELAY (Start time of each plume segment)

Line within MACCS IN1A.INP sample file:

```
RDPDELAY001      3700.    10000.
```

For a specific application:

Sequential plumes may not overlap. Therefore, the start time of each plume must be at or after the end of the preceding plume. In other words, the start time for a plume segment “i” must be ≥ the sum of the start time and release time of the previous plume segment (plume segment “i-1”).

Variable PSDIST (Dry deposition velocity bin distribution)

Line within MACCS IN1A.INP sample file:

```
RDPSDIST001      1.
RDPSDIST002      1.
RDPSDIST003      1.
RDPSDIST004      1.
RDPSDIST005      1.
RDPSDIST006      1.
RDPSDIST007      1.
RDPSDIST008      1.
RDPSDIST009      1.
```

For a specific application:

A dry deposition velocity distribution must be specified for each chemical group even if dry deposition is turned off for that group. The dry deposition bins were defined in variable VDEPOS. As discussed previously, a dry deposition velocity of 0.001 m/s is appropriate for filtered releases. Similarly, a dry deposition velocity of 0.005 m/s is an approximate value for tritiated water vapor. A dry deposition velocity of 0.01 m/s is appropriate for unfiltered releases into the environment.

Variable CORINV (Inventory available for release into the environment)

Line within MACCS IN1A.INP sample file:

```
RDCORINV001     CO-58          3.223E+16
RDCORINV002     CO-60          2.465E+16
RDCORINV003     KR-85          2.475E+16
  .
  .
  .
RDCORINV060     CM-244         2.596E+15
```

For a specific application:

Enter the radionuclides and their associated inventories for the specific application. The radionuclides here do not need to be entered in the same order as provided in the default listing.

Variable CORSCA (Inventory scaling factor)

Line within MACCS IN1A.INP sample file:

```
RDCORSCA001   0.715  *  SURRY
```

For a specific application:

This value is most often used to scale the inventory units of curies to the MACCS required value of becquerels (Bq). However, the value may be used to scale the inventory to meet any need.

Variable RELFRA (Fraction of inventory released in each plume segment)

Line within MACCS IN1A.INP sample file:

```
RDRELFRC001 1.0E+0 6.8E-1 6.4E-1 1.7E-1 4.2E-3 2.3E-3 1.6E-4 4.0E-4 6.3E-3
RDRELFRC002 4.3E-3 9.5E-3 2.4E-3 1.4E-1 6.8E-2 4.7E-4 6.8E-3 7.1E-3 5.4E-2
```

For a specific application:

A value must be specified for each chemical group and plume segments. The fraction of release is applied uniformly in to all radionuclides within a chemical group.

Output Control Data Block (OC) *NUREG/CR-4691, Vol. 1 – p. 32*

Variable ENDAT1 (Flag for Ending Code Execution)
Line within MACCS IN1A.INP sample file:

```
OCENDAT1001  .FALSE. (SET THIS VALUE TO .TRUE. TO SKIP EARLY AND CHRONC)
```

For a specific application:
Normally this value should not be changed.

Variable IDEBUG (Debug Flag)
Line within MACCS IN1A.INP sample file:

```
OCIDEBUG001  0
```

For a specific application:
Normally this value should not be changed. However, the novice use will find it helpful to set the debug to a higher value and compare the MACCS results with hand calculations using the equations in the code documentation.

Variable NUCOUT (Radionuclide to be listed on the dispersion listings)
Line within MACCS IN1A.INP sample file:

```
*OCNUCOUT001  CS-137
```

For a specific application:
Normally this value should not be changed. However, when intermediate results are desired, this value should be set equal to the dominant radionuclide.

Meteorological Sampling Data Block (M1) *NUREG/CR-4691, Vol. 1 – p. 34*

Variable METCOD (Meteorological sampling specification)
Line within MACCS2 IN1A.INP sample file:

```
* METEOROLOGICAL SAMPLING DATA BLOCK
*
* METEOROLOGICAL SAMPLING OPTION CODE:
*
* METCOD = 1, USER SPECIFIED DAY AND HOUR IN THE YEAR (FROM MET FILE),
*          2, WEATHER CATEGORY BIN SAMPLING,
*          3, 120 HOURS OF WEATHER SPECIFIED ON THE ATMOS USER INPUT FILE,
*          4, CONSTANT MET (BOUNDARY WEATHER USED FROM THE START),
*          5, STRATIFIED RANDOM SAMPLES FOR EACH DAY OF THE YEAR.
*
M1METCOD001  2
```

For a specific application:
For DSA applications, weather category bin sampling (METCOD=2) or stratified random sampling (METCOD=5) is specified.

Boundary Weather Data Block (M2) *NUREG/CR-4691, Vol. 1 – p. 36*

Note: The values in this data block must always be defined. When constant meteorological conditions are chosen (METCOD = 4), the input values represent the constant meteorological conditions. In all other cases, they represent the meteorological data if the plume has not traversed the entire grid in 120 hours.

Variable LIMSPA (Index of last radial endpoint for measured meteorological data)
Line within MACCS IN1A.INP sample file:

```
M2LIMSPA001  25
```

For a specific application:
This value should be set equal to the index of the last spatial interval

Variable BNDMXH (Boundary weather mixing layer height)
Line within MACCS IN1A.INP sample file:

```
M2BNDMXH001  1000.  (METERS)
```

For a specific application:
This value should be set equal to the appropriate mixing height for the selected stability class.

Variable IBDSTB (Boundary weather stability class)
Line within MACCS IN1A.INP sample file:

```
M2IBDSTB001  4      (D-STABILITY)
```

For a specific application:
This value should be set equal to the numeric index of the desired stability class.

Variable BNDWND (Boundary weather windspeed)
Line within MACCS IN1A.INP sample file:

```
M2BNDWND001  5.     (M/S)
```

For a specific application:
This value should be set equal to the desired windspeed.

Fixed Start Time Data Block (M3) *NUREG/CR-4691, Vol. 1 – p. 37*

Note: The values in this data block must be defined if METCOD does not equal 2 or 5.

Variable ISTRDY (Index of start day from meteorological data file)
Line within MACCS IN1A.INP sample file:

```
M3ISTRDY001  157    (START TIME FOR PEAK ECONOMIC COST OF SAMPLE PROBLEM A)
```

For a specific application:
This line should not be changed.

Variable ISTRHR (Index of start hour from meteorological data file)
Line within MACCS IN1A.INP sample file:

```
M3ISTRHR001  10     (START TIME FOR PEAK ECONOMIC COST OF SAMPLE PROBLEM A)
```

For a specific application:
This line should not be changed.

Meteorological Bin Sampling Data Block (M4) *NUREG/CR-4691, Vol. 1 – p. 38*

Variable NSMPLS (Number of samples per bin)
Line within MACCS IN1A.INP sample file:

```
M4NSMPLS001  4  (THIS NUMBER SHOULD BE SET TO 4 FOR RISK ASSESSMENT)
```

For a specific application:
This value should be set equal once to 10 and then not changed

Variable IRSEED (Random Number Generator Seed)
Line within MACCS IN1A.INP sample file:

```
M4IRSEED001   79
```

For a specific application:
This value should be selected based on the meteorological data associated with a specific location, then not changed. This is done by selecting a set of

representative base source terms, and then executing the code for each possible seed. From the resultant MOI TEDE values, the seed parameter value can be selected by the user.

EARLY Input File

Similar to the ATMOS discussion, this section of the document addresses variables that may be changed during a normal execution of MACCS 1.5.11.1 for input into a safety basis document, or must be selected by the user for a specific location. If a variable is not explicitly mentioned, it need not be changed. The particular EARLY input file commented upon here is used because it is one of the sample files (e.g., IN2A.INP) supplied with the software from RSICC.

Miscellaneous Data Block (MI) *NUREG/CR-4691, Vol. 1 – p. 46*

Variable EANAM1 (EARLY input file identifier line)
Line within MACCS IN2A.INP sample file:

```
MIEANAM1001  ' IN2A.INP, MODIFIED 6/92, SURRY, SAMPLE PROBLEM A, EARLY INPUT'
```

For a specific application:
Change to a descriptive title for this execution of MACCS

Variable IPLUME (Dispersion model option code)
Line within MACCS IN2A.INP sample file:

```
MIIPLUME001  2
```

For a specific application:

This value should be set once to 1 and then not changed.

Variable IPRINT (Debug Flag)
Line within MACCS IN2A.INP sample file:

```
MIIPRINT001  0
```

For a specific application:
Normally this value should not be changed. However, the novice use will find it helpful to set the debug to a higher value and compare the MACCS results with hand calculations using the equations in the code documentation.

Variable RISCAT (Logical flag for consequences by contribution to mean)
Line within MACCS IN2A.INP sample file:

```
MIRISCAT001   .FALSE.
```

For a specific application:
Normally this value should not be changed. However, the novice use will find it helpful to set the value to ".TRUE." and compare the MACCS results with hand calculations using the equations in the code documentation.

Variable OVRRID (Logical flag for overriding the code calculated windrose)
Line within MACCS IN2A.INP sample file:

```
MIOVRRID001  .FALSE.  (USE THE WIND ROSE CALCULATED FOR EACH WEATHER BIN)
```

For a specific application:
Normally this value should not be changed. However, if this value should be set equal to ".TRUE.", then the user-calculated windrose is inputted using the WINROS parameter that is described next.

Variable WINROS (probabilities of the wind blowing from the site into each of the 16 compass sectors (rotating clockwise from N to NNW when OVRRID parameter is set equal to ".TRUE.")

For a specific application:
Normally this parameter is not used.

Population Distribution Data Block (PD) *NUREG/CR-4691, Vol. 1 – p. 49*

Variable POPFLG (Flag indicating whether a population file of uniform population is being used)
Line within MACCS IN2A.INP sample file:

```
PDPOPFLG001  FILE
```

For a specific application:
This value should be changed once to "UNIFORM" and then not changed

Variable IBEGIN (Index of radial endpoint where the population begins)
Line within MACCS IN2A.INP sample file:

```
*PDIBEGIN001  1   (SPATIAL INTERVAL AT WHICH POPULATION BEGINS)
```

For a specific application:
This line should be changed once by removing the comment indicator (the asterisk) from the beginning of the line.

Variable POPDEN (Uniform population density of the region)
Line within MACCS IN2A.INP sample file:

```
*PDPOPDEN001  50. (POPULATION DENSITY (PEOPLE PER SQUARE KILOMETER))
```

For a specific application:
This line should be changed once by removing the comment indicator (the asterisk) from the beginning of the line, and the value changed to zero. After the line has been changed once, it will not need to be changed again.

Organ Definition Data Block (OD) *NUREG/CR-4691, Vol. 1 – p. 51*

Variable NUMORG (Number of organs to be considered)
Line within MACCS IN2A.INP sample file:

```
ODNUMORG001   10
```

For a specific application:
This value should be changed once to 2 and then not changed

Variable ORGNAM (Number of organs to be considered)
Line within MACCS IN2A.INP sample file:

```
ODORGNAM001 'SKIN', 'EDEWBODY', 'LUNGS', 'RED MARR', 'LOWER LI', 'STOMACH',
ODORGNAM002 'THYROIDH', 'BONE SUR', 'BREAST', 'BLAD WAL'
```

For a specific application:
This value should be changed to the following

```
ODORGNAM001 'NULL', 'EFFECTIVE'
```

After, the line has been changed once, it will not need to be changed again.

Shielding and Exposure Data Block (SE) *NUREG/CR-4691, Vol. 1 – p. 53*

Variable CSFACT (Cloudshine shielding factor)
Line within MACCS IN2A.INP sample file:

```
SECSFACT001      1.     0.75     0.6   *  SURRY SHELTERING VALUE
```

For a specific application:

The cloudshine shielding factor for all three activity levels should be set equal to one and then not changed.

Variable PROTIN (Inhalation protection factor)
Line within MACCS IN2A.INP sample file:

```
SEPROTIN001      1.     0.41      0.33  * VALUES FOR NORMAL ACTIVITY AND
```

For a specific application:

The inhalation protection factor for all three activity levels should be set equal to one and then not changed.

Variable SKPFAC (Skin absorption protection factor)
Line within MACCS IN2A.INP sample file:

```
SESKPFAC001  1.0      0.41     0.33    * VALUES FOR NORMAL ACTIVITY AND
```

For a specific application:

The skin absorption protection factor for all three activity levels should be set equal to one and then not changed.

Variable GSHFAC (Groundshine shielding factor)
Line within MACCS IN2A.INP sample file:

```
SEGSHFAC001      0.5    0.33    0.2   * VALUE FOR NORMAL ACTIVITY SELECTED BY
```

For a specific application:

The groundshine shielding factor for all three activity levels should be set equal to one and then not changed.

Variable BRRATE (Breathing rate)
Line within MACCS IN2A.INP sample file:

```
SEBRRATE001  2.66E-4  2.66E-4  2.66E-4
```

For a specific application:

The breathing rate for all three activity levels should be set equal to 3.33E-04 m^3/s (DOE, 1998), as discussed earlier. Note that the basis for DOE-STD-1027-92 hazard categorization is slighter higher at 3.47E-04 m^3/s.

Variable RESCON (Resuspension inhalation model concentration coefficient)
Line within MACCS IN2A.INP sample file:

```
SERESCON001   1.E-4     (RESUSPENSION IS TURNED ON)
```

For a specific application:

This value should be set once and not changed. Per DOE-3009-94 Appendix A, resuspension does not need to be included in the DSA calculations of TEDE. If resuspension is to be turned off, set the value equal to zero. If resuspension is to be applied, this value does not need to be changed.

Evacuation Zone Data Block (EZ) *NUREG/CR-4691, Vol. 1 – p. 55*

Variable LASMOV (Index of last radial ring involved in the evacuation)
Line within MACCS IN2A.INP sample file:

```
EZLASMOV001     15    (EVACUEES DISAPPEAR AFTER TRAVELING TO 20 MILES)
```

For a specific application:

This value should be set once to zero and then not changed.

Shelter and Relocation Data Block (SR) *NUREG/CR-4691, Vol. 1 – p. 58*

Variable ENDEMP (Duration of the emergency phase)
Line within MACCS IN2A.INP sample file:

```
SRENDEMP001  604800.   (ONE WEEK)
```

For a specific application:

This value should be set once to 86400 (24 hours) and then not changed. This is the minimum value allowed by MACCS2 and represent conservative implementation of the prescribed exposure duration of 2 hours (or 8 hours for slow-developing release scenarios) (DOE, 1994).

Variable TIMHOT (Time for hot-spot relocation)
Line within MACCS IN2A.INP sample file:

```
SRTIMHOT001  43200.    (ONE-HALF DAY)
```

For a specific application:

This value should be set once to 86400 (24 hours) and then not changed.

Variable CRIORG (Critical organ for relocation)
Line within MACCS IN2A.INP sample file:

```
SRCRIORG001 'EDEWBODY'
```

For a specific application:

This value should be set once to "EFFECTIVE" and then not changed.

Early Fatality Data Block (EF) *NUREG/CR-4691, Vol. 1 – p. 63*

Variable NUMEFA (Number of early fatality effects)
Line within MACCS IN2A.INP sample file:

```
EFNUMEFA001   3
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Early Injury Data Block (EI) *NUREG/CR-4691, Vol. 1 – p. 67*

Variable NUMEIN (Number of early injury effects)
Line within MACCS IN2A.INP sample file:

```
EINUMEIN001  7
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Latent Cancer Data Block (LC) *NUREG/CR-4691, Vol. 1 – p. 69*

Variable NUMACA (Number of acute exposure cancer effects)
Line within MACCS IN2A.INP sample file:

```
LCNUMACA001   7
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type One Output - Health Effects Data Block (T1) *NUREG/CR-4691, Vol. 1 – p. 75*

Variable NUM1 (Number of requested outputs)
Line within MACCS IN2A.INP sample file:

```
TYPE1NUMBER    27
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type Two Output – Early Fatality Radius Data Block (T2) *NUREG/CR-4691, Vol. 1 – p. 77*

Variable NUM2 (Number of requested outputs)
Line within MACCS IN2A.INP sample file:

```
TYPE2NUMBER  1
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type Three Output – Population Exceed Dose Threshold Data Block (T3) *NUREG/CR-4691, Vol. 1 – p. 78*

Variable NUM3 (Number of requested outputs)
Line within MACCS IN2A.INP sample file:

```
TYPE3NUMBER  3
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type Four Output – Average Individual Risk Data Block (T4) *NUREG/CR-4691, Vol. 1 – p. 79*

Variable NUM4 (Number of requested outputs)
Line within MACCS IN2A.INP sample file:

```
TYPE4NUMBER  5
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type Five Output – Population Dose Data Block (T5) *NUREG/CR-4691, Vol. 1 – p. 81*

Variable NUM5 (Number of requested outputs)
Line within MACCS IN2A.INP sample file:

```
TYPE5NUMBER     3
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.

Type Six Output – Centerline Dose at Distance Data Block (T6) *NUREG/CR-4691, Vol. 1 – p. 82*

Variable NUM6 (Number of requested outputs)
Line within MACCS IN2A.INP sample file:

```
TYPE6NUMBER     0
```

For a specific application:
This value should be set equal to the number of desired results.

Variable ORGNAM, PATHNM, I1DIS6, and I2DIS6 (Organ name, pathway name, inner spatial interval, and outer spatial interval as input by OUT)
Line within MACCS IN2A.INP sample file:

```
*TYPE6OUT001  'RED MARR'    'TOT ACU'      1       19     (0-50 MILES)
*TYPE6OUT002  'LUNGS'       'TOT ACU'      1       19     (0-50 MILES)
*TYPE6OUT003  'EDEWBODY'    'TOT LIF'      1       26     (0-1000 MILES)
```

For a specific application:

The comment indicator (the asterisk) should be removed from the output definition. The organ name should be change to "EFFECTIVE". The pathway name should be changed to "TOT LIF". The inner and outer spatial intervals (radii) should be set equal to the ring encompassing the receptor location. If the release is elevated or heated and the MOI is located within several kilometers of the release location, the MOI may not be located at the closest site boundary but at the point of plume touch down. In this case, the inner and outer spatial intervals should be reset to encompass the location of the plume touch down.

Type Seven Output – Centerline Risk vs. Distance Data Block (T7) *NUREG/CR-4691, Vol. 1 – p. 84*

Variable NUM7 (Number of requested outputs)
Line within MACCS IN2A.INP sample file:

```
TYPE7NUMBER     0
```

For a specific application:

This value should not be changed.

Type Eight Output – Population Weighted Risk Data Block (T8) *NUREG/CR-4691, Vol. 1 – p. 86*

Variable NUM8 (Number of requested outputs)
Line within MACCS IN2A.INP sample file:

```
TYPE8NUMBER   2
```

For a specific application:

This value should be set once to zero and the rest of the lines within the block should be commented out and then not changed.